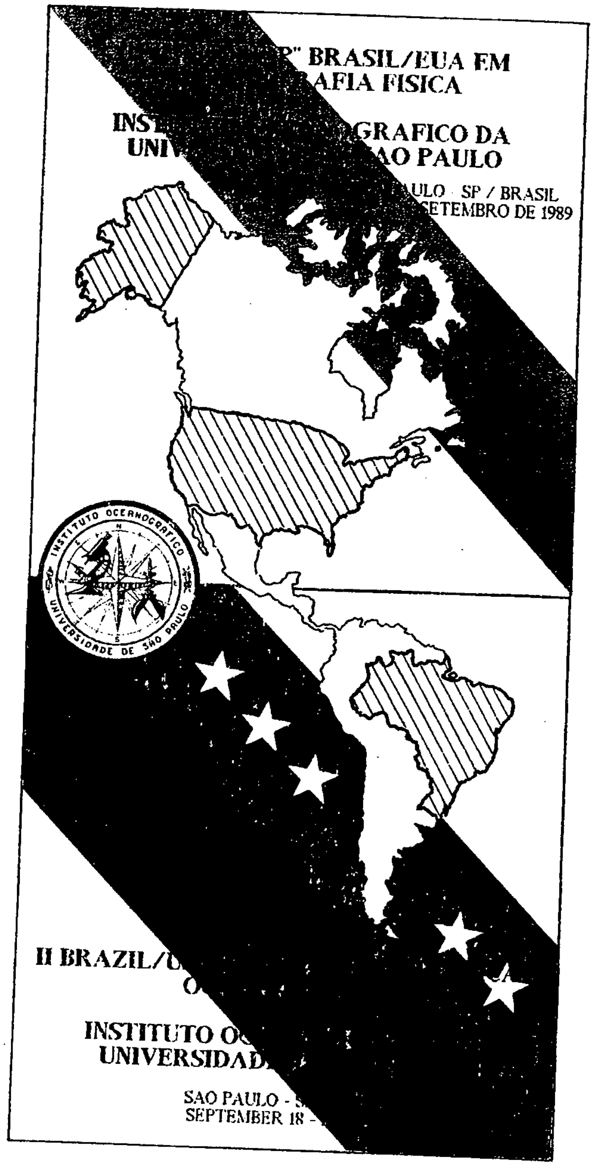

Report of the SECOND BRAZIL/U.S. WORKSHOP ON PHYSICAL OCEANOGRAPHY

held

18-21 September 1989

at the

Institute of Oceanography
University of São Paulo
São Paulo, Brazil

CONVENED BY:
Affonso da S. Mascarenhas, Jr.
University of São Paulo
Wendell S. Brown
University of New Hampshire

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Instituto Oceanográfico da Universidade de São Paulo
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ORGANIZED BY:

IOUSP – **Local Organizing Committee, SP, Brazil**
- **Affonso da S. Mascarenhas, Jr.**
- **Luiz Bruner de Miranda**
- **Belmiro Mendes de Castro Filho**
- **Nuno Pereira Filho**
- **João Antonio Lorenzzetti (INPE)**

UNH – **University of New Hampshire, Durham, NH, USA**
- **Wendell Brown**
- **Frank Smith**

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TABLE OF CONTENTS

I. INTRODUCTION

The Second Brazil/U.S. Workshop on Physical Oceanography was held September 18-21, 1989, at the Instituto Oceanográfico, Universidade de São Paulo (IOUSP), Brazil. It was a followup to a workshop held at the University of New Hampshire in August 1987, at which 5 Brazilian and 25 U.S. physical oceanographers met to present results of work in the tropical and South Atlantic Oceans, identify major scientific questions about the physics of that region of the world's oceans, and begin discussions of collaborative research opportunities to address those questions. By convening the 1989 workshop in São Paulo, organizers were successful in involving a much larger segment of the Brazilian physical oceanographic community (see Appendix A for a list of registrants).

During the first two days of the workshop, participants presented results of collaborative work conducted in the interim between the two workshops. Extended abstracts of these presentations appear in Section II, below. Wednesday and Thursday were dedicated to discussions (see Section III) of strategies for resource and data sharing; dovetailing experimental designs to minimize duplication and maximize complementarity; and developing joint research initiatives. On Friday, U.S. participants toured the oceanographic and meteorological laboratories of the Brazilian Institute for Space Research at São José dos Campos. The full program of workshop activities is detailed in Appendix B.

II. WORKSHOP ABSTRACTS

HYDROGRAPHIC OBSERVATIONS IN THE AMAZON OUTFLOW, AUGUST, 1989

RICHARD LIMEBURNER
ROBERT BEARDSLEY
Woods Hole Oceanographic Institution

AMASSEDS is a multidisciplinary investigation of physical, geological, and chemical processes within the Amazon dispersal system. There is a complex interplay between shelf circulation and mixing and the geological and geochemical processes occurring over the Amazon subaqueous delta. Vast quantities of water, sediment, and terrigenous chemical species are carried across the shelf over the delta, and their fate depends critically on the currents and turbulence on the shelf. As part of AMASSEDS, a physical oceanography component plans to (a) make four regional hydrographic/ADCP surveys and release surface drifters (August, 1989; February, June, 1990; November, 1991), (b) deploy a two-element moored array of current meters and one wind recorder (February-June, 1990), and (c) conduct two small-scale studies of the salinity front (February, June, 1990). In addition, theoretical work has been started to build simple models of the regional tidal currents and the Amazon front.

Hydrographic observations were made in the Amazon outflow over the Brazil shelf during August 4-10, 1989 as part of A Multidisciplinary Amazon Shelf SEDiment Study (AMASSEDS). During this first AMASSEDS cruise on the R/V *Iselin*, 86 CTD/light transmission profiles were obtained over a sampling grid of seven cross-shelf transects located between the equator and 5°N. During this time of falling river outflow, the Amazon River discharge formed a large low-salinity plume over the adjacent shelf, with a well-defined front separating the low-salinity core of the plume (with salinity less than 20°/₀₀) from the North Brazil Current (NBC) water found over the mid- and outer shelf and slope (with salinity greater than 35.5°/₀₀). Using the 32°/₀₀ isohaline surface to define the center of the salinity front, the base of the front closely followed the 15-25m isobaths, while at the surface the front spread far offshore in the downstream direction (see Figures 1a and 1b). Between 3° and 4°N, the 32°/₀₀ isohaline surface had an average inclination of 1.4×10^{-4}. The light transmission data showed that the most turbid water was found inshore of the base of the salinity front. In addition, two satellite-tracked surface drifters drogued at 5 m were deployed in the Amazon outflow between 0° and 1°N. These drifters moved northwest over the shelf at $1 - 2$ m s^{-1} until about 7°N, where both were carried offshore and southeast in a large clockwise arc often referred to as the North Brazil Current retroflection (see Figure 2). These observations support the hypothesis of Muller-Karger et al. (1988) that Amazon water is injected into the western tropical North Atlantic by retroflection of the NBC.

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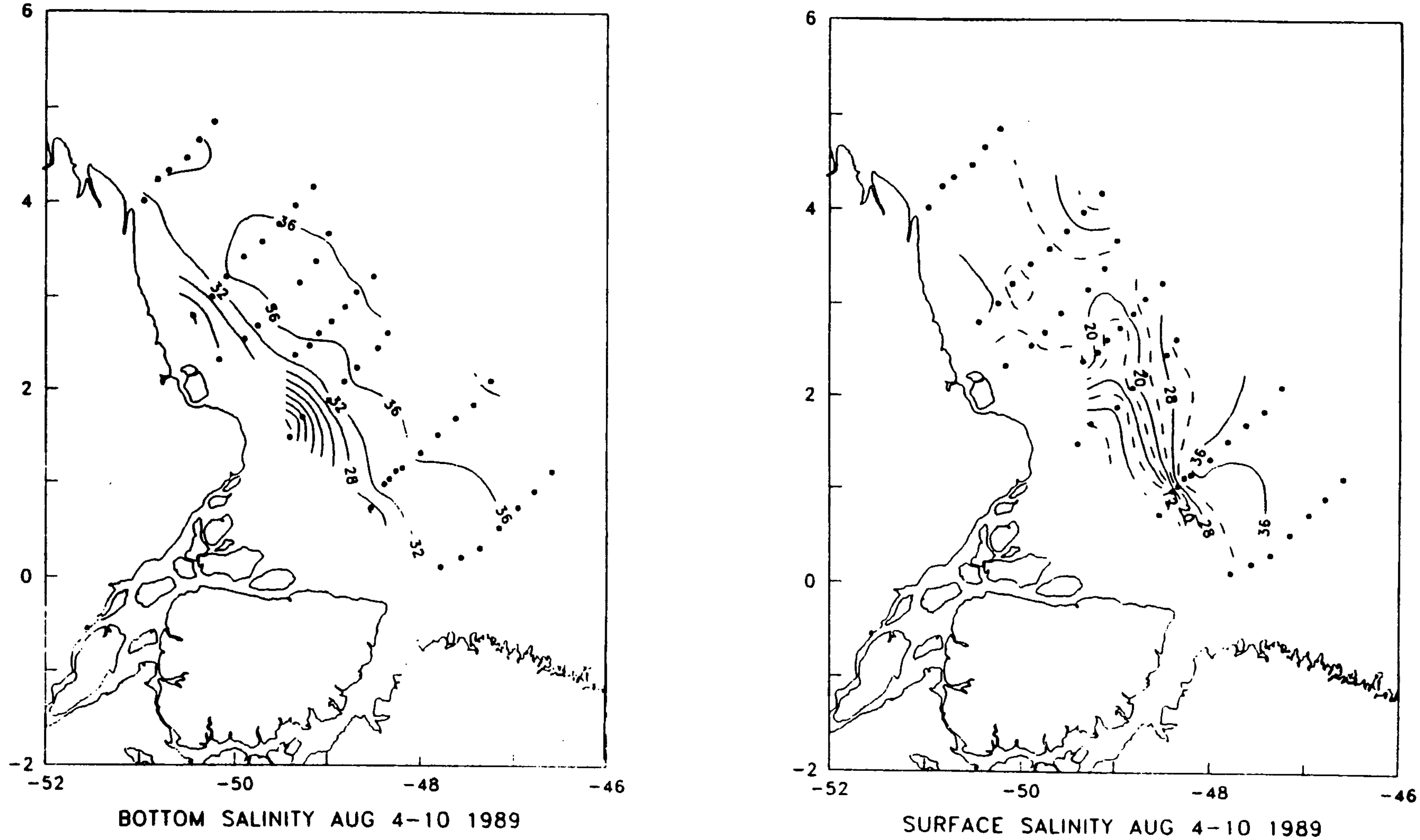
Muller-Karger, F.E., C.R. McClain, and P.L. Richardson, The dispersal of the Amazon's water, *Nature, 333*(6168), 56-59, 1988.



Figures 1a and 1b. Bottom and surface salinity from R/V *Iselin* cruise I8909 during August 4-10, 1989.

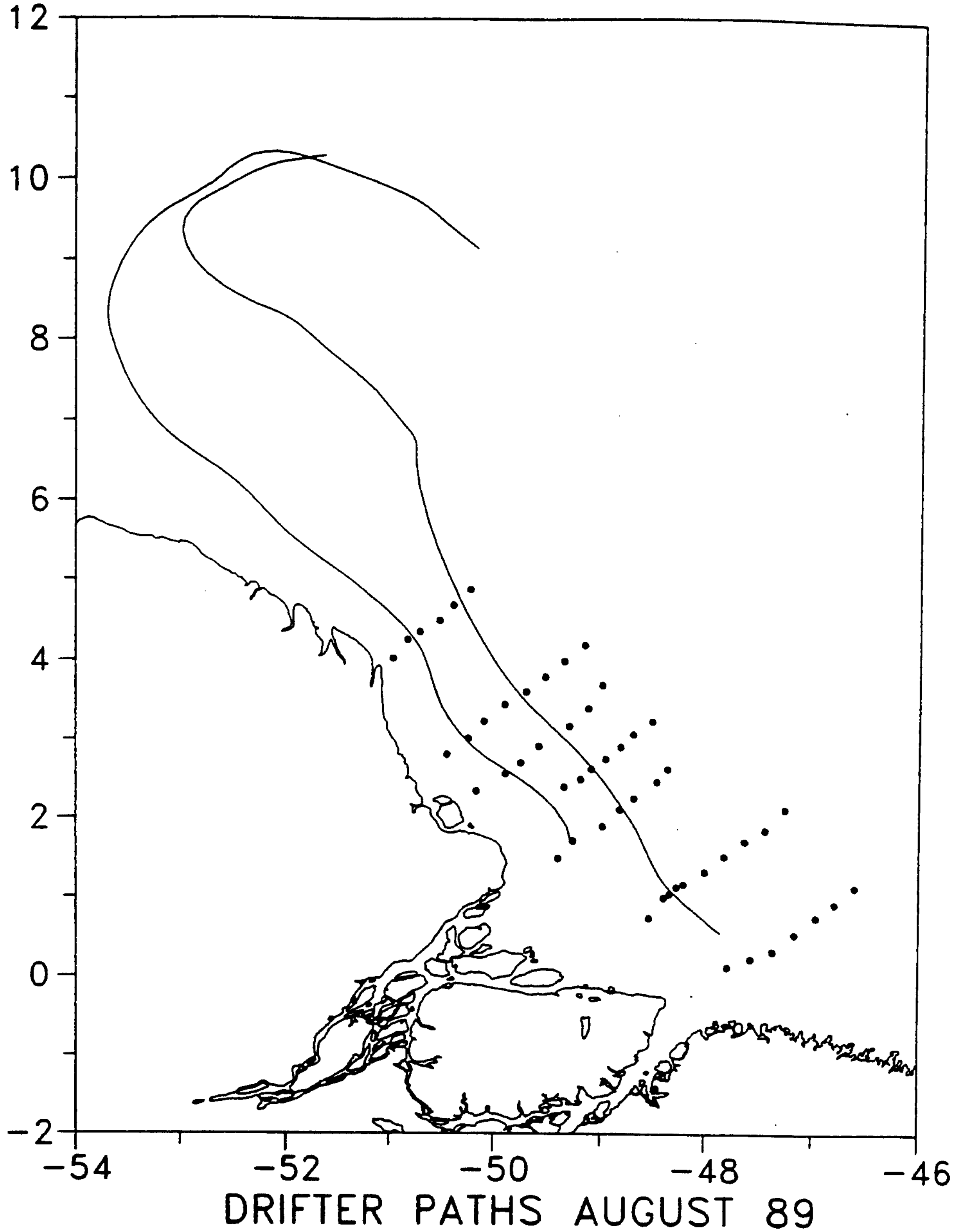


Figure 2. Filtered trajectories of satellite-tracked drifter buoys drogued at 5 m during August 7-30.

OCEANIC TIDES

AFRANIO R. DE MESQUITA
JOSEPH HARARI
Instituto Oceanográfico
Universidade de São Paulo

Historically, the physics of oceanic tides start in modern times with Sir Isaac Newton (in 1687 with the *Principia*), who laid down the basic gravitational laws of the tide-generating potential. The long-lasting succession of contributions on tides sums up nearly three hundred years of tide research. A lucid historical review on oceanic tides is given by Cartwright (1977).

Tides are measured throughout the world on all continents and several oceanic islands via permanent tide stations on piers or other fixed installations. About 840 tide series are reported by the Permanent Service for the Mean Sea Level (PSMSL) (Pugh et al., 1988). Non-permanent stations are also occupied for tidal measurements (one month to one year of hourly observations). Pelagic station measurements are among the non-permanent series which are helping to further understanding of the real oceanic tides. Pelagic and satellite altimetry measurements are envisaged as the fundamental tools in the effort to understand and predict global oceanic tides in the near future. Such an enormous task will require the effort of many individuals and scientists for several years to come. In Figure 1 are shown aspects of the working area of the PAVASAS project (Amphidromic Points and Seasonal Variations of the South Atlantic), which has been carried out since 1976 with the objective of contributing to that effort along the Brazilian coast.

To improve the understanding of oceanic tides, the physics of the nonlinear processes related to the generation of shallow water components needs to be better known. Internal tides are considered as one of the possible processes whereby tides are dissipated, as energy goes from lower to higher frequency tidal bands, by advection. The amount of tidal energy absorbed by friction is also a matter of concern. Estimates based on a mean current speed over the shelf areas and the quadratic law for the friction term, in Laplace's tidal equation of motion, give negligible values at the open sea, compared to those estimated at the shelf areas. If the advection terms for shelf waters and the open sea area were larger than the frictional terms in the processes of generating higher order tidal components, tidal energy dissipation rates of these terms would be necessarily different from the present estimated values. Cartwright (1977), reviewing the matter, identified a tidal energy "gap" between the work done by the sun and the moon on the sea and the amount of energy dissipated by the tides. Estimates of Lambeck (1977), however, based on satellite observations and numerical models found a balance, $4.1 \pm 0.4 \times 10^{12}$ watts and $4.5 \pm 0.5 \times 10^{12}$ watts, for the forces transferred to and dissipated by the oceans. Whatever the real values for the balance, there remains doubt about the rates at which ocean tide advection and

friction intervene in the total budget of energy flow. Evidence indicates that in the open ocean internal tides may absorb the tidal energy; Figure 2 shows the residual energy from Inverted Echo-Sounder data with tidal analysis centered in the semidiurnal, terdiurnal, fourth diurnal, and sixth diurnal bands (Franco et al., 1988) at Atlantic equatorial waters; that residual energy results directly from the generation of shallow water spectral bands. Analysis of temperature time series of the same area also indicates tidal energy being dissipated at higher order tidal harmonics as depicted in Table 1 (Mesquita et al., 1988). Spectral analysis of tidal data of the southeastern Brazilian shelf shown in Figure 3 suggests also the occurrence of higher order harmonics related to dissipation by advection. These results—interpreted by a perturbation approach applied to pelagic measurements, the tidal equations of Laplace, and using a formulation of Godin and Gutierrez (1986) for shallow water components with even order—tend to be stronger than those of friction (odd order) on the Brazilian southern shelf area.

Approaches by Gallagher and Munk (1971) and Franco (1988) on the generation of shallow water components from the equations of motion, and the ones which take into consideration the bottom boundary and the tidal forcing, are among the prospects for a continued progresson oceanic tides.

The ultimate goal of science, prediction, is well underway in the present due to continued refinements of tidal analyses for long tidal records. For the South Atlantic, from nineteen years of hourly observations, these analyses (Franco and Harari, 1988) show new shallow water components for the southeastern shelf area of Brazil increasing the predictive capacity via non-parametric physical models. For the southeastern area, predictions for harbors of Cananeia and Ubatuba are regularly made by Mesquita and Harari (1988); for most of the remaining harbors shown in Figure 1, tide predictions are published by DHN (Diretoria de Hidrografia e Navegação) of the Brazilian Navy.

Tide predictions by numerical models on a global scale have greatly improved (Schwiderski, 1980), but close to the coast where dissipation is more effective, such models differ a lot. For the southeast coast of Brazil, pelagic data (Fig. 1) has been successfully used for the prediction of currents and tidal heights, as shown in Figure 4 (Harari, 1985). Further work aims also at reproducing such predictions via numerical models for all coastal areas around Brazil, where pelagic and coastal data are available as depicted in Figure 1.

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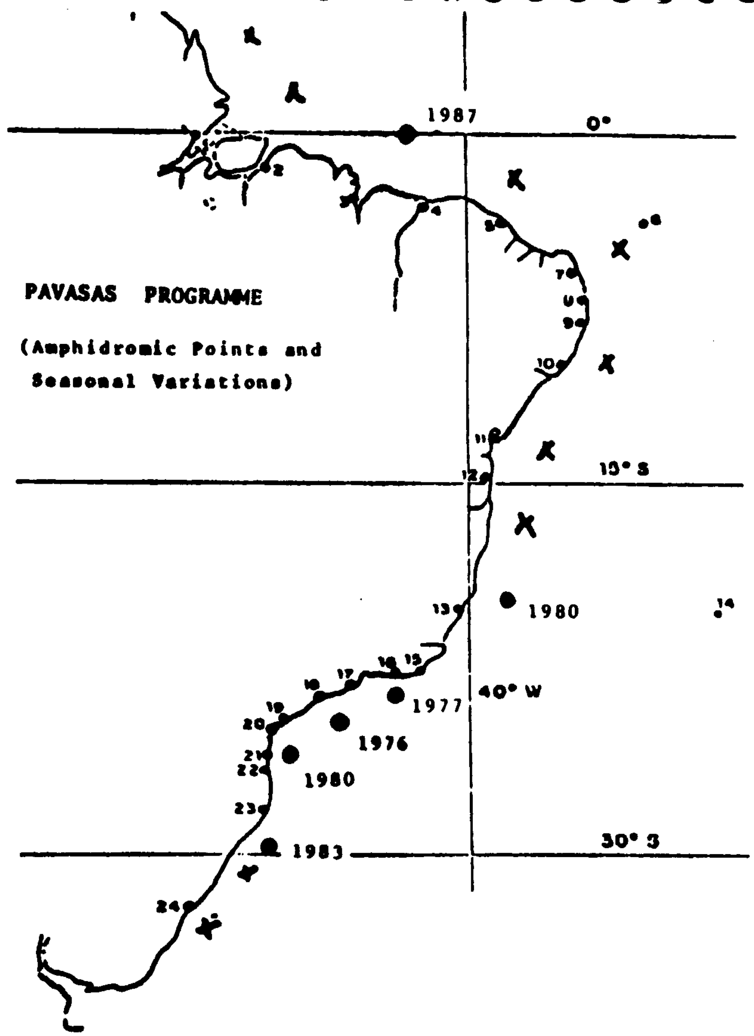

PERMANENT STATIONS

No	Tidal stations	Lat.		Long.	
1	Santana	00°	0,2'S	51°	0,6'W
2	Belem	01	30	48	30
3	Itaqui (Maranhão)	02	36	44	18
4	Luiz Correia (PI)	02	54	41	42
5	Fortaleza	03	42	32	30
6	Fern. de Noronha	03	40	32	24
7	Natal	05	48	35	12
8	Cabedelo	07	06	34	54
9	Recife	08	02	34	54
10	Maceió	09	36	35	42
11	Itaparica	13	00	38	36
12	Ilhéus	14	48	39	00
13	Vitória	20	18	40	18
14	Trindade	20	30	29	18
15	Cabo Frio	23	00	42	00
16	Ilha Fiscal	22	48	43	12
17	Ubatuba	23	24	45	06
18	Santos	23	54	46	24
19	Cananéia	25	06	47	54
20	Paranaguá	25	30	48	30
21	S. Francisco do Sul	26	18	48	36
22	Itajaí	26	54	48	42
23	Imbituba	28	18	48	42
24	Rio Grande	32	06	52	06

Figure 1. (left) Geographical distribution of the main tidal stations along the Brazilian coast. (right) Pelagic tidal measurements (non-permanent stations): • – measurements taken; X – planned measurements.

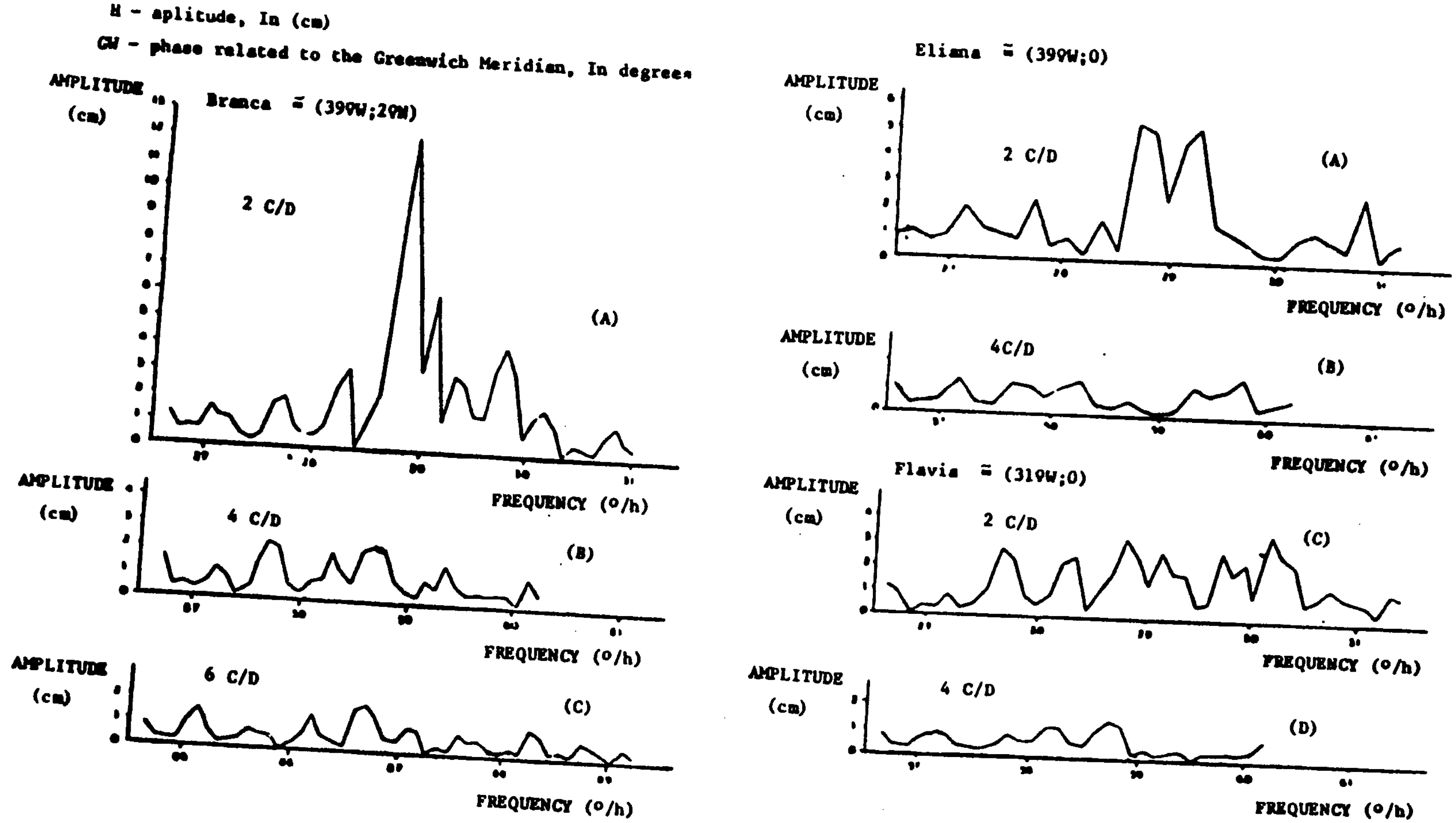

Figure 2. (left) Amplitude residual spectrum for "Branca" Station: 2 C/D (A), 4 C/D (B) and 6 C/D (C). (right) Amplitude residual spectrum for "Eliana" Station: 2 C/D (A) and 4 C/D (B); for "Flavia" Station: 2 C/D (C) and 4 C/D (D).

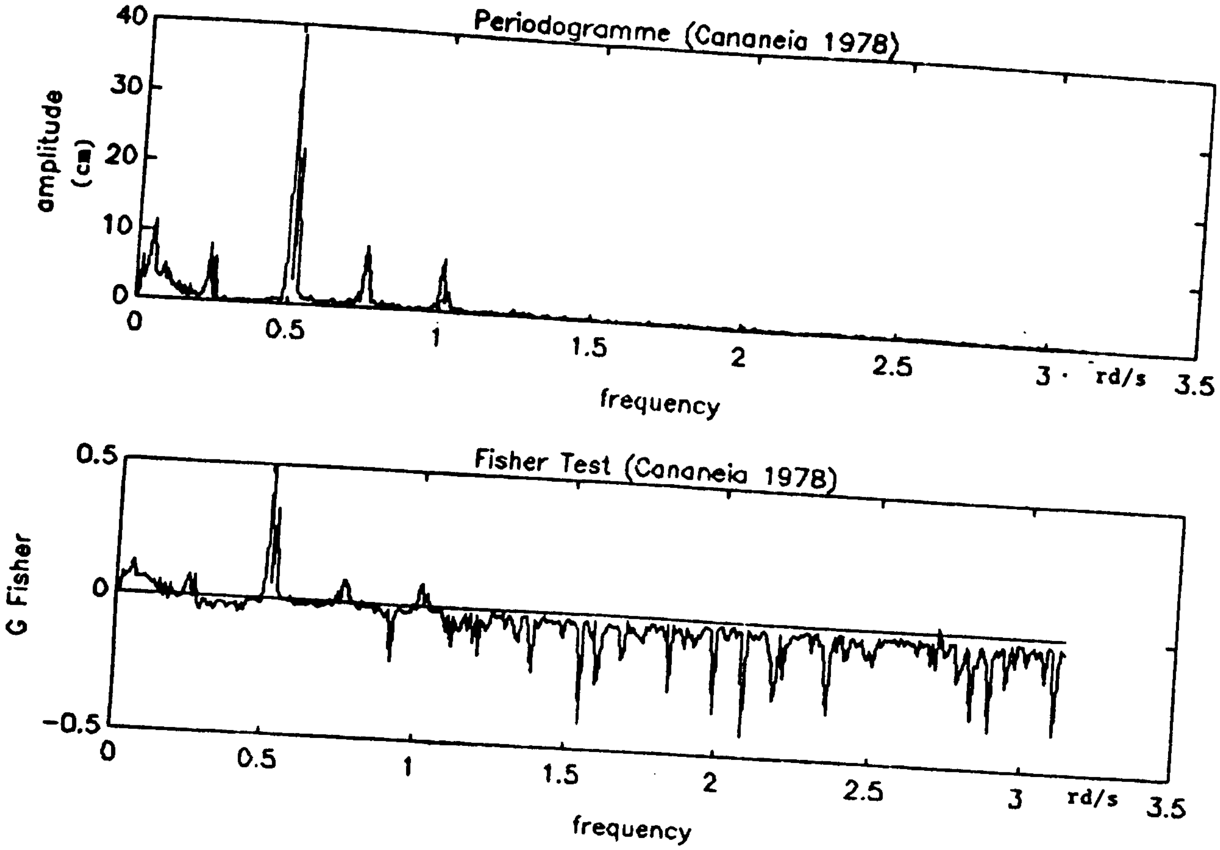

Figure 3. Periodogramme of tidal data of Cananéia and the corresponding Fisher's tests. Only the fourth diurnal tidal band passes the test among the shallow water constituents.

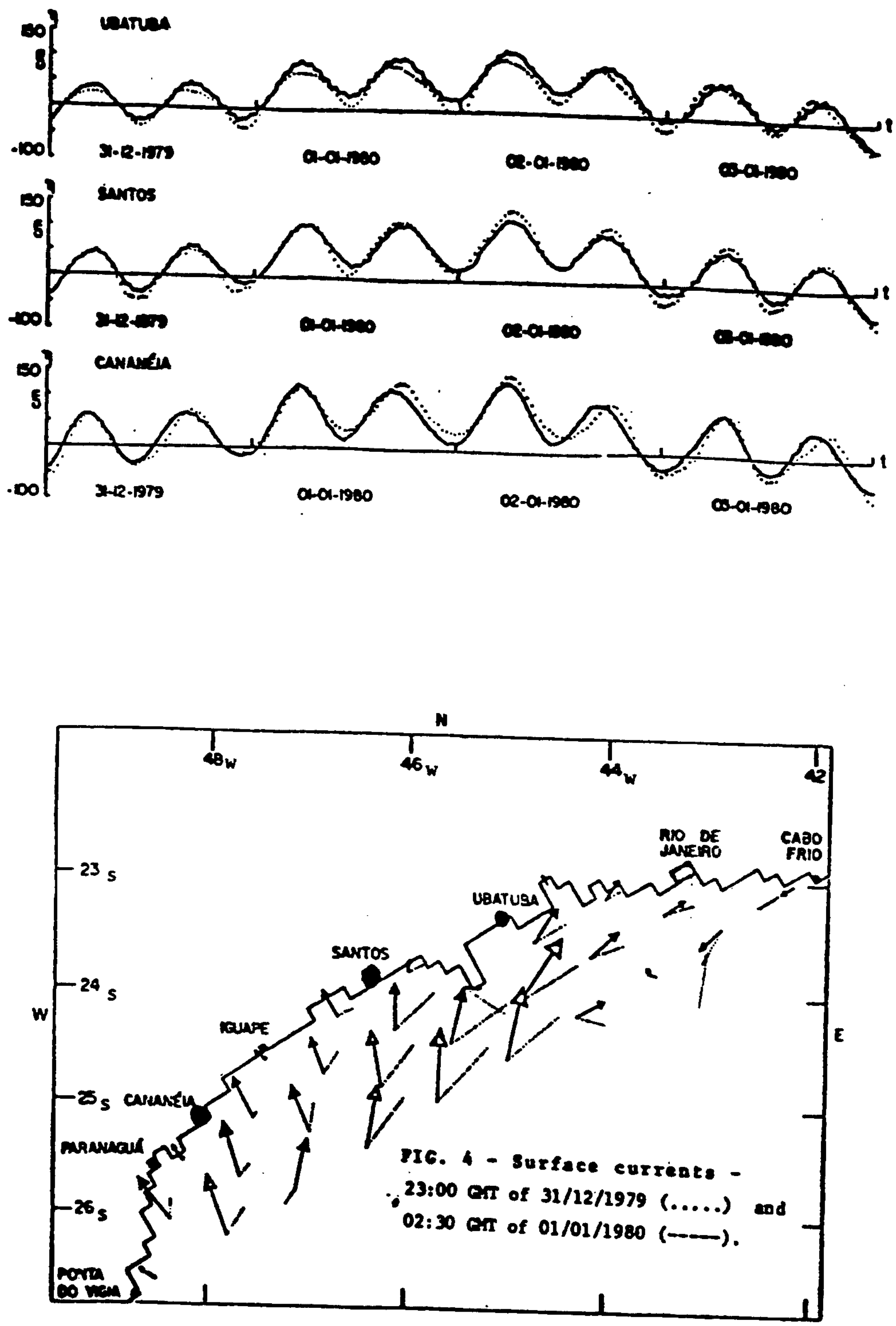

Figure 4. (above) Tidal heights: model (- - - -), observation (. . . . . .). (below) Surface currents: 23:00 GMT of 31/12/1979 (. . . . . .) and 02:30 GMT of 01/01/1980 (- - - -).

"Alme Saldanha" - PHASE III - Oct. 1974

Periodicities

mean series	layer 60-110m		difference	
	4/4	3/4		
15.3	16.7	-	-1.1	
6.3	-	6.4	-0.1	
3.3	3.3	-	0.0	
1.5	1.4		+0.1	days
1.3	-	1.3	0.0	
1.1	-	1.1	0.0	
22.4	-	22.5	-0.1	- diurnal
20.5	20.9	-	-0.4	
18.7	-	18.8	-0.1	
17.6	17.7	-	-0.1	
16.1	16.3	-	-0.2	
15.0	-	15.2	-0.2	
13.9	-	13.9	0.0	
13.1	13.1	-	0.0	
12.6	-	12.7	-0.1	- semidiurnal
11.4	-	11.6	-0.2	
10.5	10.8	-	-0.3	
9.6	-	9.7	-0.1	hours
9.1	-	9.1	0.0	
8.7	-	8.8	-0.1	
8.4	-	8.5	-0.1	- terdiurnal
8.0	8.1	-	-0.1	
7.7	-	7.8	-0.1	
7.4	-	7.4	0.0	
7.2	7.2	-	0.0	
6.9	-	6.9	0.0	
6.5	-	6.6	-0.1	
6.3	6.4	-	-0.1	- quarterdiurnal
6.1	-	6.2	-0.1	

Table 1. Maximum entropy spectral periods of temperature "mean" series of equatorial layer of 60 to 110 m, (35°W; 2°N) compared with the spectral summary of four original temperature series of the same layer. The columns 4/4 and 3/4 indicate the number of occurrences of a spectral period in four possibilities. The column "difference" shows how different the period estimates of the two methods are.

MIXING IN THE AMAZON PLUME: SOME EARLY RESULTS OF AMASSEDS

WAYNE GEYER
Woods Hole Oceanographic Institution

One of the principal objectives of the AMASSEDS Program is to examine the mechanisms of mixing between the fresh waters of the Amazon plume and the Atlantic water on the north Brazilian continental shelf. While the major field effort directed at this problem will occur during 1990, the results of the August, 1989 cruise provide some insight into the exchange processes.

Using the equation for salt conservation following the plume from the river mouth, the increase in salinity of the brackish layer can be related to the entrainment across the pycnocline

$$u_1 h_1 \frac{\partial S_1}{\partial x} = w_{up}(S_2 - S_1)$$

where u_1 and h_1 are the velocity and thickness of the upper layer, S_1 and S_2 are the salinities in the upper and lower layers, and w_{up} is the upward entrainment across the interface. The entrainment rate is directly related to the buoyancy flux

$$B = g w_{up}(\rho_2 - \rho_1) = \beta g w_{up}(S_2 - S_1)\,,$$

where β is the proportionality factor between salinity and density. The salinity gradient and velocity can then be used to obtain a direct estimate of buoyancy flux

$$B = \beta g u_1 h_1 \frac{\partial S_1}{\partial x}$$

The buoyancy flux is related to the total production of turbulent kinetic energy via the flux Richardson number

$$Rf = \frac{B}{\tau \partial u / \partial z}$$

Experiments and field observations have indicated that Rf is less than 10^{-2} for boundary layer flows (Hearn, 1984), and it has a maximum value of approximately 0.15 in the case of shear-induced mixing in the ocean (Osborn, 1980). Using the maximum value of 0.15, a lower bound on the turbulent energy production can be determined for a given buoyancy flux. This in turn can be used to constrain the value of the interfacial stress, providing some insight into the plume dynamics. The limitations of this approach are 1) that the velocity and salinity distributions can be approximated by two layers, and 2) that the salt flux into the plume is accomplished due to vertical entrainment rather than horizontal mixing.

Two ARGOS-tracked drifters, drogued between 2.5 and 7.5 m depth, were released near the mouth of the Amazon River at the beginning of a hydrographic survey conducted during the period of 3-10 August, 1989 (see Limeburner and Beardsley, this volume). While the drifters did not measure salinity, the hydrographic survey provides an indication of the variation of salinity along their trajectories, from which the salinity gradient could be estimated. The drifters lagged the shipboard measurements by 1-3 days, so there may have been some temporal variation in the salinity structure, but the general characteristics of the salinity variation along the drifter tracks should be reasonably well represented. The hydrographic data did not show a clear two-layer structure; the region above the pycnocline tended to have continuous stratification. However, the strong halocline could be used to distinguish the upper and lower portions of the water column and so to apply the above salt balance relationship.

Drifter 1, which was released in the freshwater plume, showed a rapid increase in salinity over the first 70 km of its trajectory, increasing from 0 to 20°/₀₀. Drifter 2, released to the SE of the river mouth, decreased in salinity from 30 to 20°/₀₀ as it approached the latitude of the north channel, after which it increased slightly to 22°/₀₀. The variation in salinity of drifter 2 is likely the result of transverse convergence of Amazon plume water and north Brazilian shelf water, and it does not indicate energetic mixing in that portion of the plume. However, the variation in salinity of drifter 1 is roughly consistent with the vertical entrainment model proposed above, and an estimate of the buoyancy flux can be obtained from the salinity data and the velocity of the drifter. Based on the above equation for B, the buoyancy flux for the first 70 km of the drifter's trajectory is $1.2\text{-}2.4 \times 10^{-5}$ m^2 s^{-3}. By comparison, the buoyancy flux associated with net heating in this region is nearly 3 orders of magnitude smaller. The mechanism by which this large buoyancy flux is accomplished appears not to be the direct result of bottom-generated turbulence, since it is too inefficient at converting kinetic to potential energy to account for the volume of entrainment that is accomplished in this region. Rather, it appears that shear-induced mixing within the pycnocline supplies the energy for mixing, since it can convert as much as 15% of the turbulent kinetic energy to buoyancy flux.

While the conclusions of this preliminary study are very tentative, the more detailed study to occur in the frontal zone in 1990 should provide the required resolution of the velocity and density variations to specify the mechanisms of mixing between fresh and salt water and their influence on the distribution of sediment in the dispersal system.

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ON THE VARIABILITY OF THE MEAN SEA LEVEL ON COASTAL AREAS

JOSEPH HARARI
AFRANIO RUBENS DE MESQUITA
Instituto Oceanográfico
Universidade de São Paulo

The mean daily sea levels of the southeastern Brazilian shelf from Paranaguá to Santos vary in a similar way and are excited by the passage of atmospheric frontal systems (Fig. 1). Periodicities of 3 to 6 days are also observed in time series of currents, temperature, and salinity of the region. The mean monthly levels from Piraquera (Ilha Grande Bay), Ubatuba, Santos and Cananéia (Fig. 2; Franco and Mesquita, 1986) have a similar variation and show four peaks during the year: in February, April-May, August, and November. The February peak is strongly related to the seasonal solar heating, while that of April-May is apparently caused by the action of the winds that displace the tropical waters against the coast in this epoch of the year. The secondary peaks of August and November are apparently more associated with the large scale oceanic variations that show a strong interannual variability. The seasonal mean sea level variation on the southeastern coast is similar to the ports of Recife, Salvador, and Imbituba. The monthly sea levels of the northern coast seem to have a different seasonal behavior from those of the southeastern coast (Fig. 3; Mesquita et al., 1986).

The long-term sea level trend seems to show an accentuated increase in the more recent years, as pointed out by Barnett (1983). The mean value of the secular variation calculated for the southeastern coast of Brazil is about 30 cm/century, with a background of the order of 10 cm/century, from the variation along the South American coasts and the Atlantic coast of Africa.

A formal relationship seems to occur between the length of the series and C (its regression coefficient against the time), indicating that the negatively and positively trended series of the relative mean sea level (rmsl) are varying in an almost corresponding way so as to compensate for the extreme negative and

positive values of C (Fig. 4), producing a small overall mean global variation in C of 10 cm/century.

Another relation appears to occur between the correlation coefficient m (of the data and its linear regression) and the values of C, indicating that both species of trended series may be increasing their rates of C in recent years, as already pointed out (Fig. 5; Mesquita and Leite, 1986).

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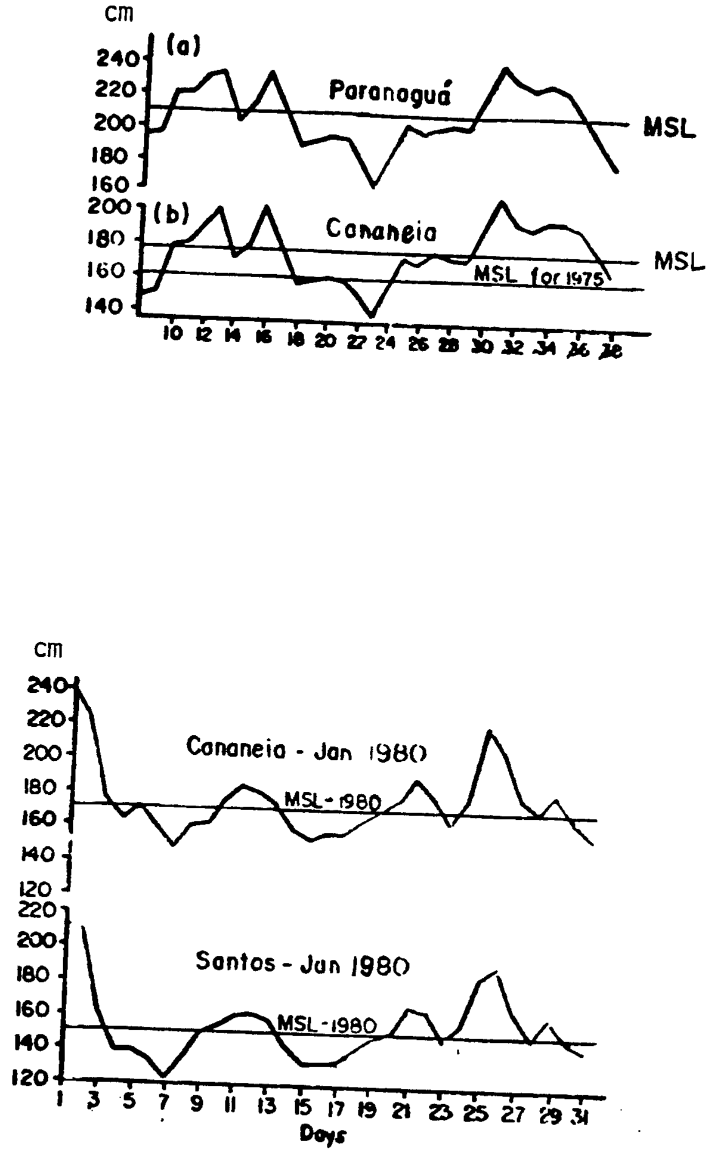

Figure 1. (above) MSL (cm) at Paranaguá and Cananéia from 8/4 to 8/5/1975. (below) Filtered daily values of MSL (cm) for Cananéia and Santos (Franco and Mesquita, 1986).

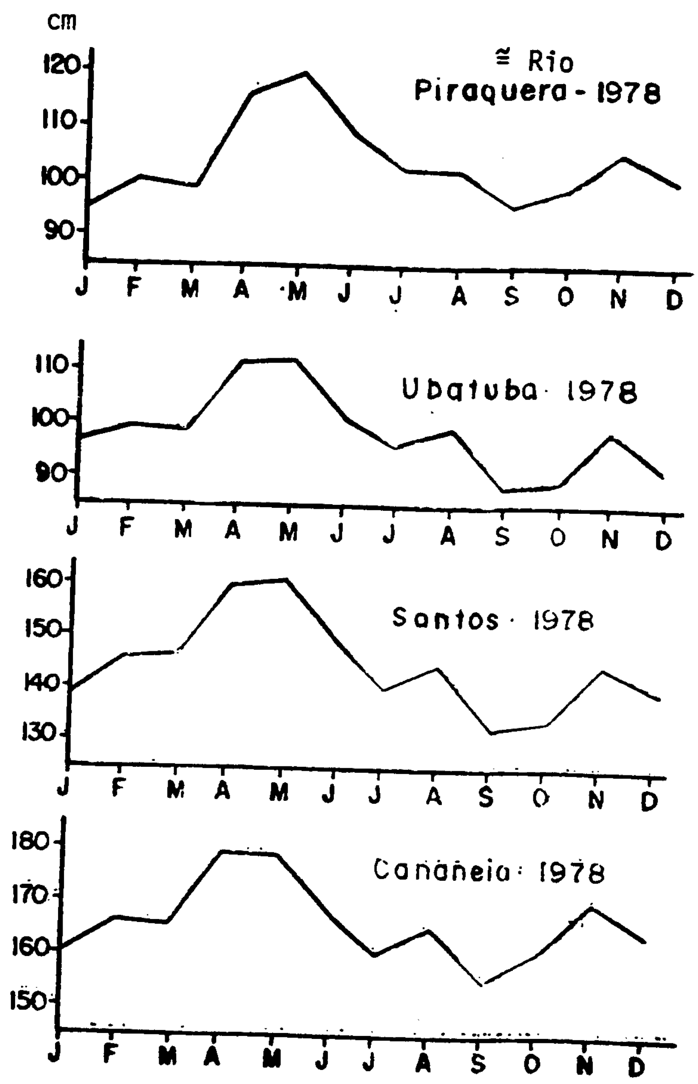

Figure 2. Monthly mean sea levels (cm). (After Franco and Mesquita, 1986.)

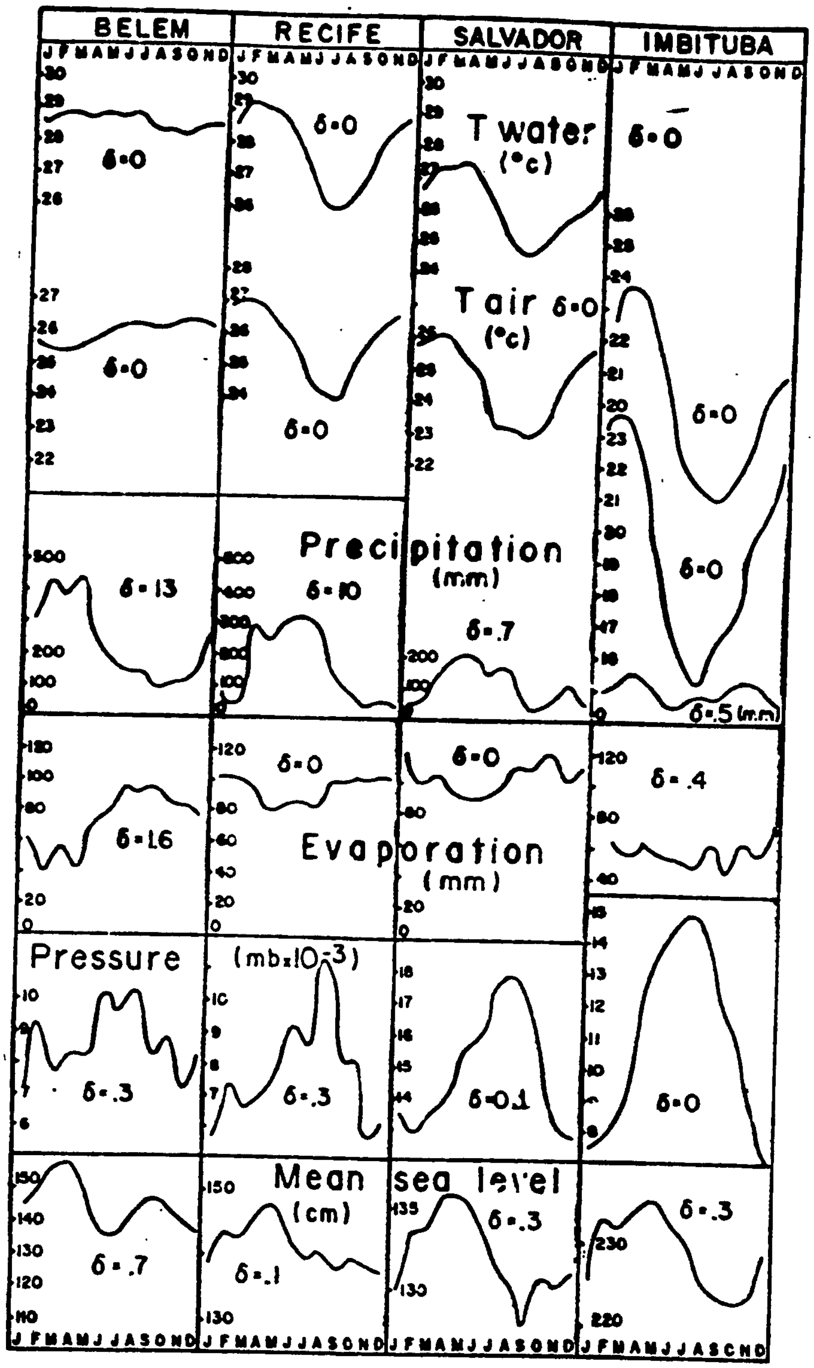

Figure 3. Mean monthly values of mean sea level (cm), air temperature, sea temperature (°C), atmospheric pressure (mb), precipitation and evaporation (mm)—from 1953 to 1962—at Belém, Recife, Salvador and Imbituba. δ is the difference between the "Fourier fit" and the data. (After Mesquita et al., 1986.)

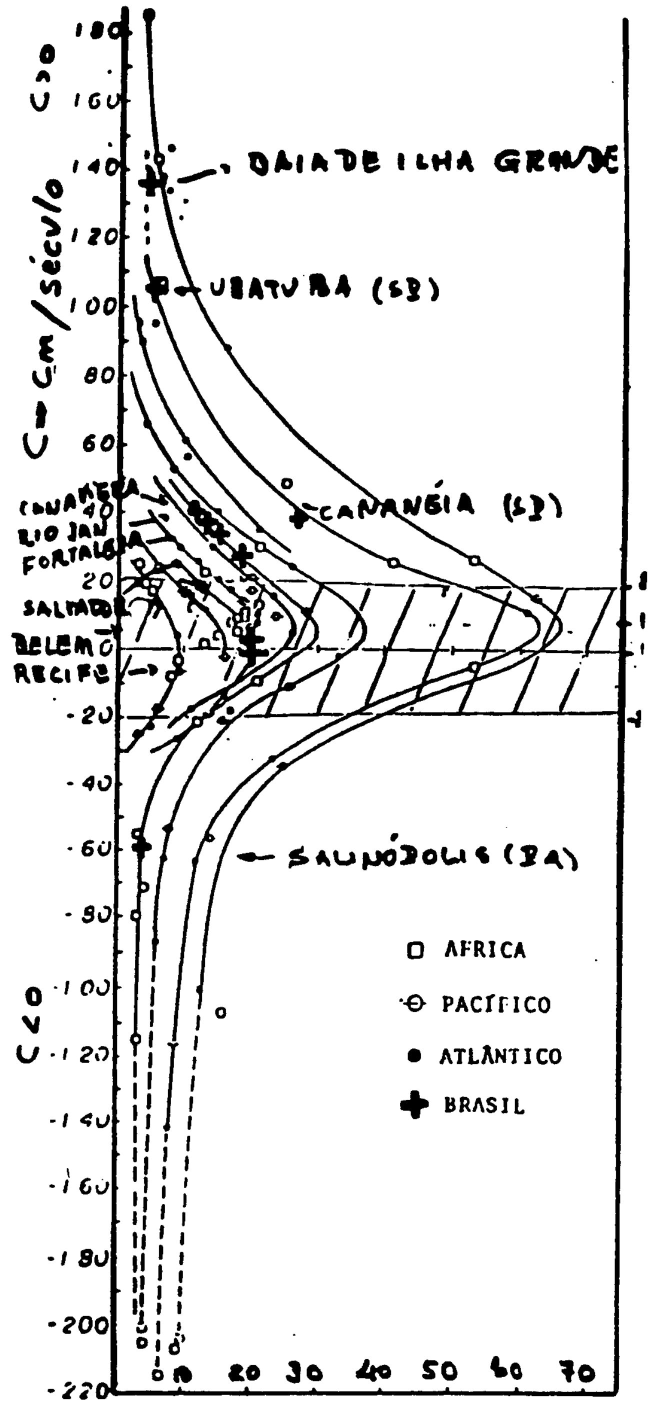

Figure 4. Values of the regression coefficients C plotted against the length of the series for ports of Brazil, Atlantic, Pacific and Africa. Lines joining the points are hypothetical, indicating that the relative mean sea levels of the above ports way follow an expression as $L = N\,exp[-(C-10)^2/\alpha]$, where N is the maximum number of years of the chosen line, 10 cm/cy is the approximate value of the global rmsl, α is a constant, and L is the length of the series with trend C. (After Mesquita and Leite, 1986.)

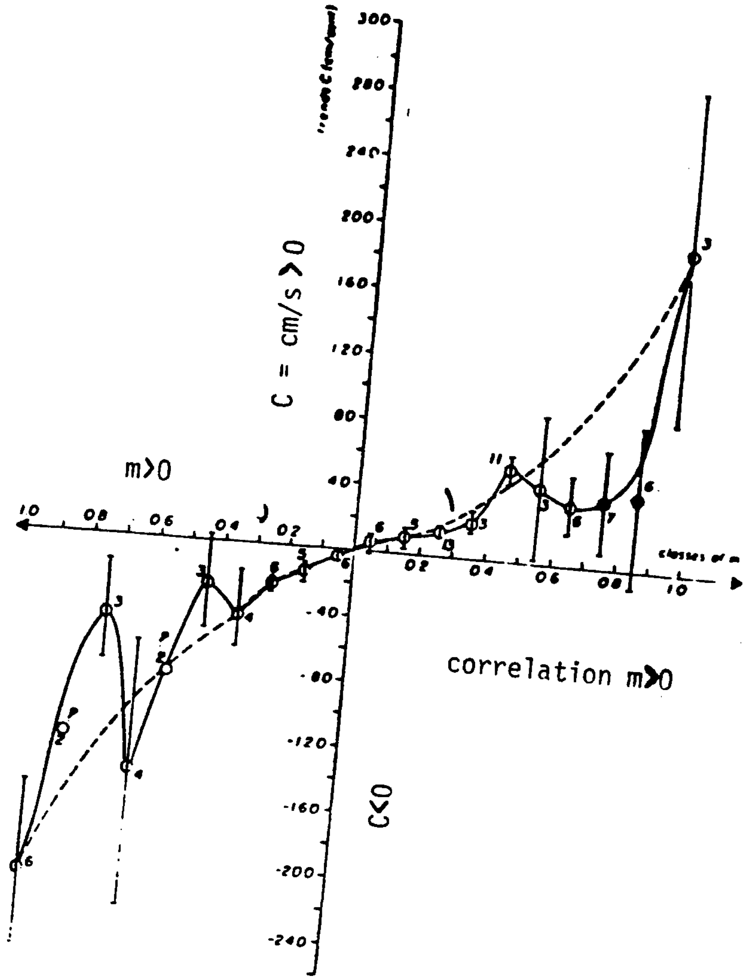

Figure 5. Value of C, regression coefficient of the annual series of relative mean sea level, plotted against the correlation coefficient (m) of the data of a series and its regression lines. Numbers indicate how many series were taken into account to calculate the error bars (standard deviations σ). Values of m were grouped into ten classes from 0 to 1.0, and then (σ) values were calculated from the corresponding values of C for each class. The dashed line may be following the expression $|C| = a\,exp[\beta m] - a$, where a is a constant (cm/cy), β is another constant, and m correlation coefficient above defined. For high m values correspond high positive and negative values of C, while for $m = 0$, $C = 0$. (After Mesquita and Leite, 1986.)

NEAR EQUATORIAL EDDIES OFF SOUTH AMERICA

JOHN G. BRUCE
U.S. Naval Oceanographic Office

The near equatorial eddies off the northeast coast of South America are associated with the convergence-divergence and mixing of several water types. Considerable variability, particularly seasonally, occurs here. In the surface layers the North Brazilian Current (NBC) flows northwest along the coast from the southern hemisphere and is observed to turn in part offshore, combine with the southern branch of the North Equatorial Current (NEC), then loop south and eastward into the North Equatorial Counter Current (NECC).

The near-synoptic airborne expendable bathythermograph (AXBT) surveys by the Naval Oceanographic Office (NAVOCEANO) in this region can be used to estimate the eddy-like circulation patterns (anticyclonic) during the seasonal extremes (March and September) both in the upper mixed layer (retroflection) and the layer in the lower thermocline where a degree of recirculation occurs in the northern (5°N–10°N) and southern (2°N–5°N) eddies off the coast. Other earlier surveys in this region, although not necessarily designed to study the eddy field, allow estimates of volume transport associated with the eddies to be calculated. An example being that during February-March, the northern eddy transport (0-400 dbar, rel. 800 dbar) is 10 to 14 $\times 10^6$ m^3 s^{-1}, whereas during late summer and autumn it is 25 to 30 $\times 10^6$ m^3 s^{-1} with a considerable portion of this supplying the NECC.

At various levels, both salinity and dissolved oxygen serve to trace circulation patterns of this region. The relatively fresh and plankton-rich Amazon outflow advected offshore in the surface water of the northern eddy gives a strong signal in a map of surface salinity or CZCS imagery. The subtropical underwater salinity maximum shows the NEC convergence with the northern eddy. Both O_2 minimum and maximum sources are useful in tracing the southern eddy where it turns offshore (below the mixed layer) near 5°N.

The seasonal cycle of the mean wind stress pattern for the region off the coast of NE South America has opposite extremes during northern spring and fall. When the ITCZ is nearly aligned along the equator during spring, the relatively strong onshore NE wind dominates the coast with wind stress values from 0.5 dyn cm^{-2} near the equator to over 2.0 dyn cm^{-2} near 6°N–7°N. (Here, estimates were made from Hastenrath and Lamb, 1977. Slightly lower values were determined by Hellerman, 1979, using Bunker's calculations). By northern fall, however, the ITCZ reaches about 8°N–10°N off the coast, and local winds here are $<$ 0.5 dyn cm^{-2} and have an alongshore component to the NW.

Surface currents from historical data such as H.O. 571 indicate a strong northwestward component throughout the year located generally along the shelf edge. The strongest flow occurs during August-October with monthly means $>$ 100 cm s^{-1} from 0°–5°N. A somewhat similar pattern but with weaker currents

is found during northern spring. Inshore of the shelf edge in the region of the Amazon basin, measurements by Gibbs (1982) indicate a considerable onshore tidal component coupled with the alongshore flow.

Past surveys (Ryther et al., 1967; Metcalf, 1968; Cochrane, 1969, 1975; Bruce, 1984; Bruce et al., 1984), particularly two airborne AXBT studies during March and September 1983, indicate that this strong coastal current, the North Brazilian Current (NBC), is associated with a large eddy region which extends from approximately 2°N to 11°N off the NE South American coast. Although the circulation pattern of the eddies appears to be relatively complex and variable, maps of the isotherms at depths within the main thermocline (Robinson et al., 1979) suggest that off the coast two semi-permanent, anticyclonic eddy-like features are formed. The southern feature (sometimes referred to as the Amazon eddy) tends to be formed off the shelf between 2°N–6°N by a branch of the NBC (particularly the subsurface portion) turning eastward offshore near the Amazon Cone. Another eddy to the north (6°N–11°N) often (but not always) turns offshore near the Demarara Rise (off Surinam). A major portion of this eddy appears to be composed of mixed layer and upper thermocline water, and its circulation generally does not penetrate as deeply as the southern eddy. Both eddies seem larger (~400 km across), deeper, and have a greater volume transport during August–October.

The 20°C isotherm lies about in mid-thermocline (Bruce, 1984), and maps giving its depth during spring and fall (March and September 1983, NAVOCEANO AXBT surveys) indicate the approximate general circulation pattern of the anticyclonic features. The surface and mixed layer (~upper 125 m) of the northern eddy, however, tends to turn offshore, loop around to the south and then turn eastward as a source of the North Equatorial Countercurrent (NECC) during late summer–early fall. This pattern is illustrated by maps of the temperature at 100 m depth (Fig. 1). Below this layer (>125 m), however, the eddy flow tends to recirculate, being somewhat more contained, as suggested by maps of temperature at 200 m depth (Fig. 2).

The relatively fresh Amazon outflow water advected north by the nearshore portion of the NBC serves as an excellent tracer during the fall for the surface water of the northern eddy as it loops around and enters the NECC. A map of surface salinity from the *Alaminos* 1964 survey combined with a 1983 NORDA section (Fig. 3) at nearly the same time of year (July) clearly shows the flow pattern. The 1983 data were used because the fall 1983 NAVOCEANO temperatures appear to fit well with those of the 1964 *Alaminos* maps of temperature at mixed-layer and mid-thermocline depths. In the *Alaminos*-NORDA map, the low salinity water is seen to be advected clockwise around the northern and eastern edge of the northern eddy. It is then carried eastward (with surface salinity < 32‰ near 5°N to 7°N) in the strong NECC.

Although the northern eddy is observed during the spring, the strong onshore wind forcing from the NE trades prevents the fresh water from being advected very far offshore. A certain portion, however, is observed in the northern edge of

the northern eddy in a May 1983 *Oceanus* section extending meridionally along 52°W through the northern eddy (Fig. 4). The surface geopotential anomaly and salinity plotted together clearly show the fresh band of Amazon origin water in the west-going coastal flow. Then, on the northern side of the eddy (where the geopotential is strongly decreasing northward), the surface salinity is also relatively fresh in this eastward flow. Thus, even during spring conditions, the northern eddy apparently influences somewhat the seaward dispersion of Amazon-type water. The CZCS imagery clearly shows the retroflecting loop during fall but also suggests faintly that a portion of the surface water is advected around by the northern eddy during spring. While Amazon origin water can be carried eastward in the northern eddy, still an amount is forced northward as shown by June-August 1969 observations of surface salinity (Mazeika, 1973). During the hydrographic survey at that time, five research vessels on anchor station recorded surface salinity. All observed lower ($< 35°/_{oo}$) values, particularly the *Discoverer* at 13°08'N, 53°51'W, which recorded salinities at $< 31°/_{oo}$ with considerable high frequency (hours) variability, this position being 1500 km from the Amazon delta.

The geostrophic volume transport values during late summer–fall (*Alaminos* 1964 survey; Fig. 5) in the upper 0–150m layer tend to be large compared to the 150–400m transport values. On the coastal side of the northern eddy, the upper layer transport amounts to 20×10^6 m^3 s^{-1}. It would seem that about 11×10^6 m^3 s^{-1} looped around eastward and then flowed southward (this water has essentially the same T-S characteristics as that on the western side of the eddy), leaving about 9×10^6 m^3 s^{-1} to continue northwestward along the coast. (This splitting of the coastal current can be observed clearly in the CZCS imagery.) On the eastern boundary of the eddy there appears to be a converging flow with the North Equatorial Current (NEC), which loops around cyclonically (counterclockwise) and merges with the flow of the northern eddy. The combined transport is 21×10^6 m^3 s^{-1}. Farther to the east, additional flow from the NEC and also the southern eddy reaches transport values of 28×10^6 m^3 s^{-1}. However, recirculation back into the NEC and southern eddy then reduces the eastward transport into the NECC to 14×10^6 m^3 s^{-1} near 37°W.

Volume transport values during late winter–spring (Crawford, 1968 survey; Fig. 6) are lower than those during fall (order 20 to 50%), although seasonal comparison with the few existing sets of observations is tenuous at best due to the considerable short-term variability which can occur within this eddy region.

Maps of geopotential anomaly of 200 dbar relative to 800 dbar for both *Alaminos* 1964 and *Crawford* 1968 surveys (Fig. 7) suggest that below the mixed layer a considerable amount of water from the NBC turns offshore into the southern eddy. Maps of dissolved oxygen at 200 m and 400 m also show that much of this lower layer, with higher O_2 values in the NBC from the southern hemisphere, is mixed into the southern eddy, some of which flows eastward in the Equatorial Undercurrent (EUC).

The pattern of mixing southward of the NEC where a branch converges

with the eastern edge of the northern eddy is seen by maps of salinity at 100 m depth (using the subtropical underwater salinity maximum to help trace the flow). Also, the O_2 minimum water advected westward by the NEC is useful as a tracer.

Although considerable variability occurs in the structure of the northern and southern eddies both seasonally and interannually, a number of surveys in the eddy region all indicate that these features tend to be semi-permanent. In addition to the two NAVOCEANO AXBT surveys, the Alaminos 1964 and that of Crawford 1968, there have been Brazilian studies: *Almirante Saldanha*, Jul–Aug 1973, May–June 1976; and *Silva*, 1958. There have also been cruises by the Netherlands during fall 1970 and spring 1971 on H.R.M.S. *Luymes.*

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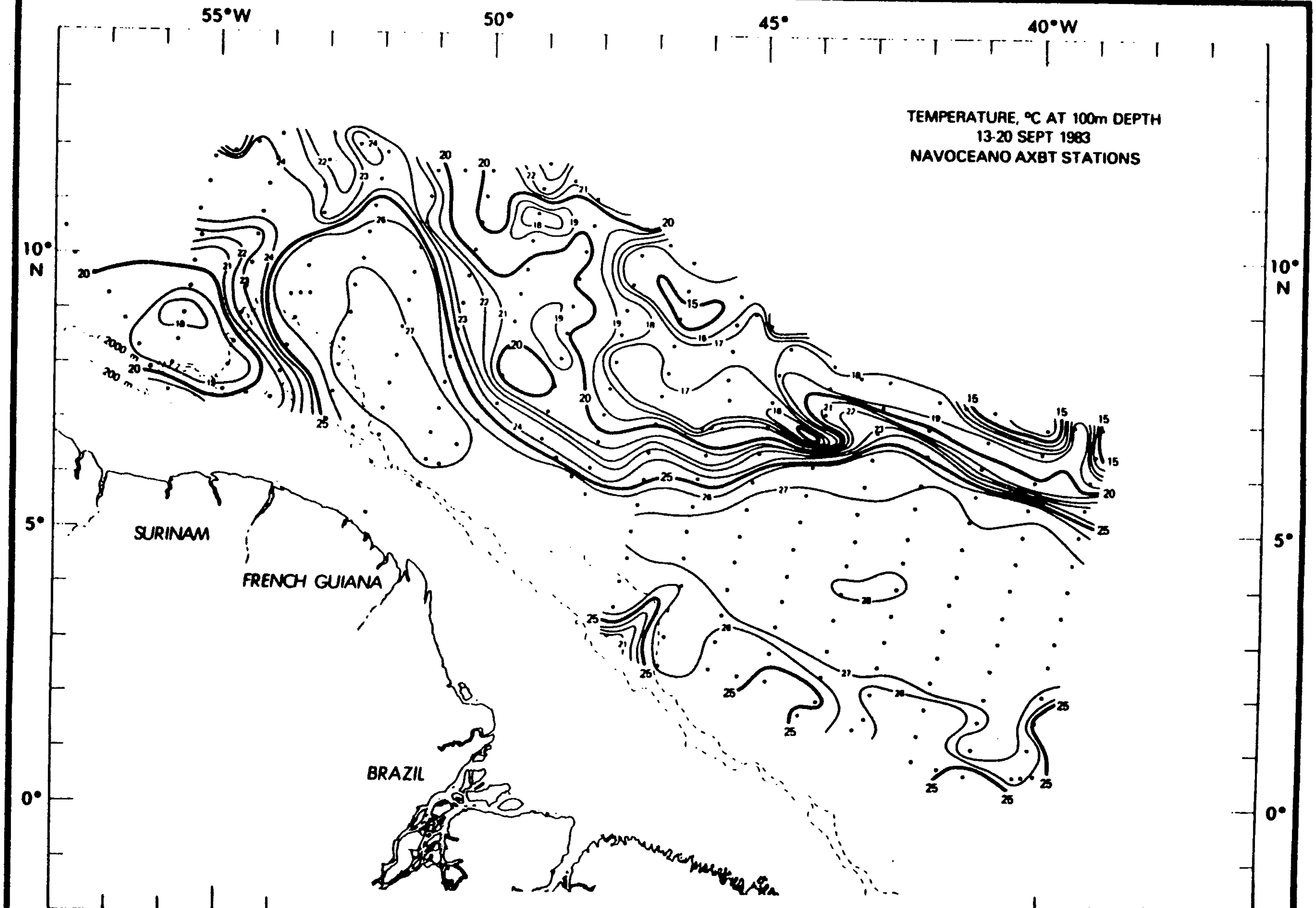

Figure 1. Temperature, °C, at 100 m depth from AXBT survey by NAVOCEANO, 13-20 September 1983. Isotherm contours indicate approximate circulation pattern for upper layer, with flow diverging from coast and looping clockwise to eastward and then south.

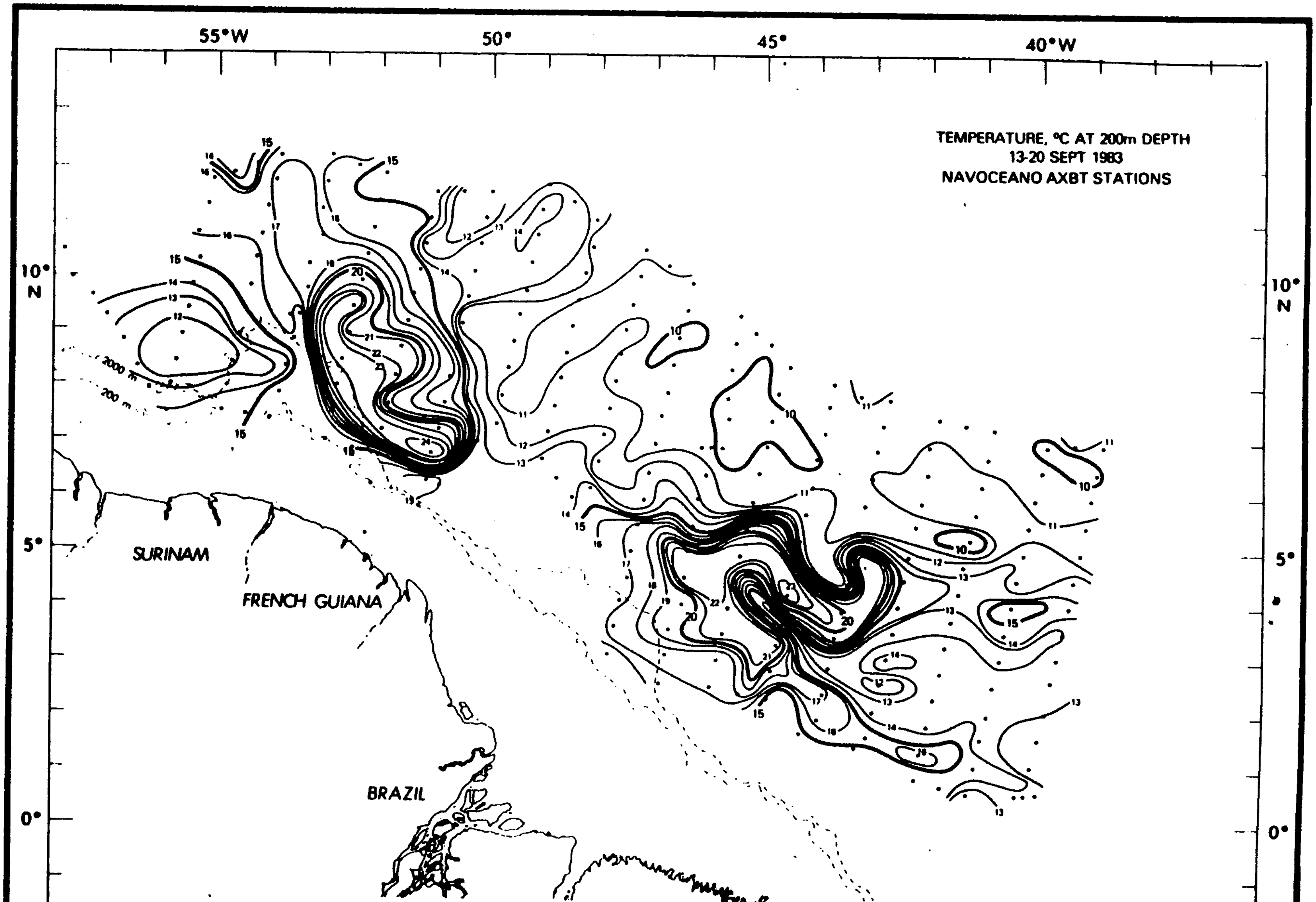

Figure 2. Temperature, °C, at 200 m depth from AXBT survey by NAVOCEANO, 13-20 September 1983. Circulation pattern for lower layer (below mid-thermocline depths) is approximated by isotherm contours showing considerable recirculation within eddy structure.

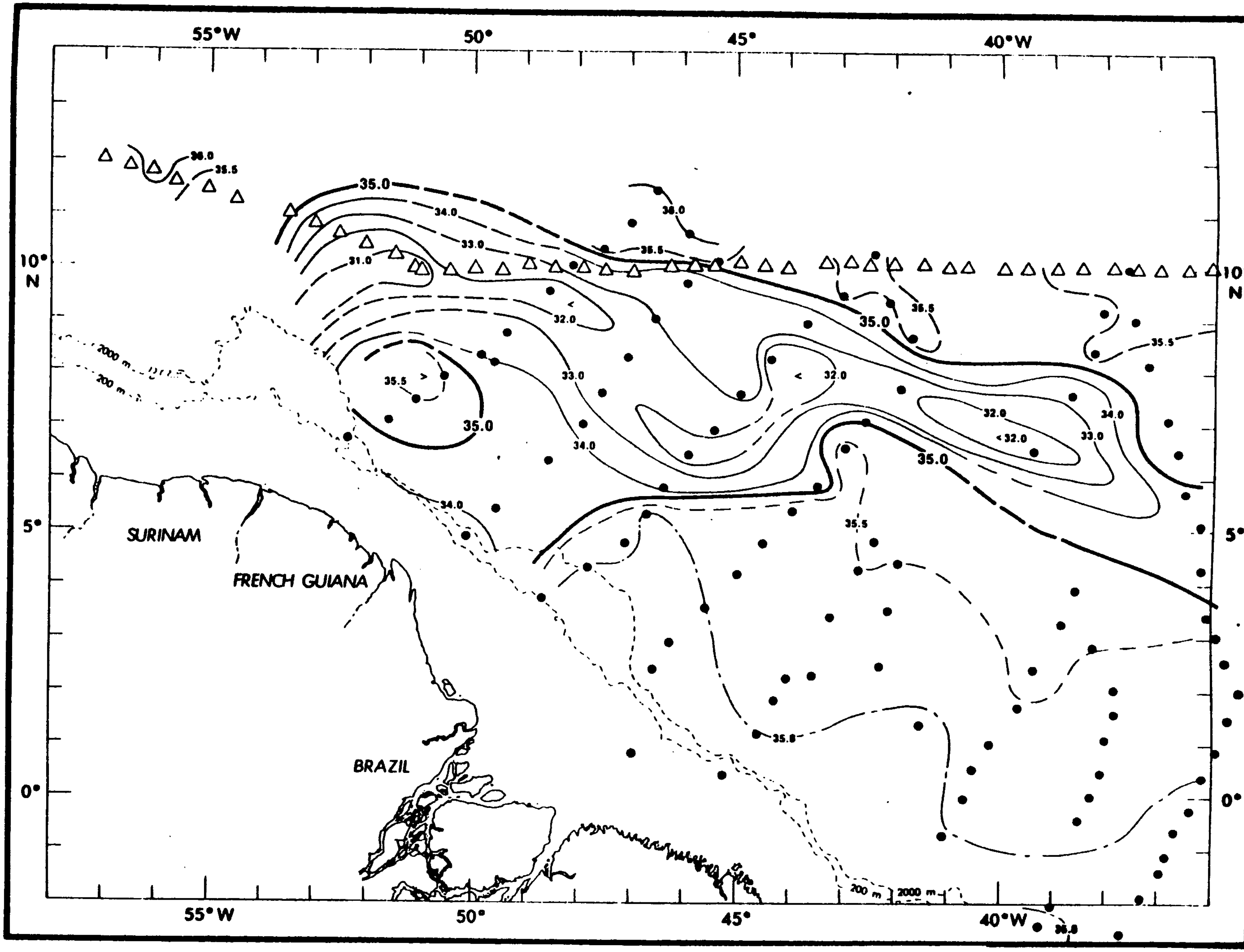

Figure 3. **Surface salinity, °/₀₀.** *Alaminos*, 31 July-10 September 1964, dots. NORDA (USNS *Lynch*), 22-29 July 1983, triangles.

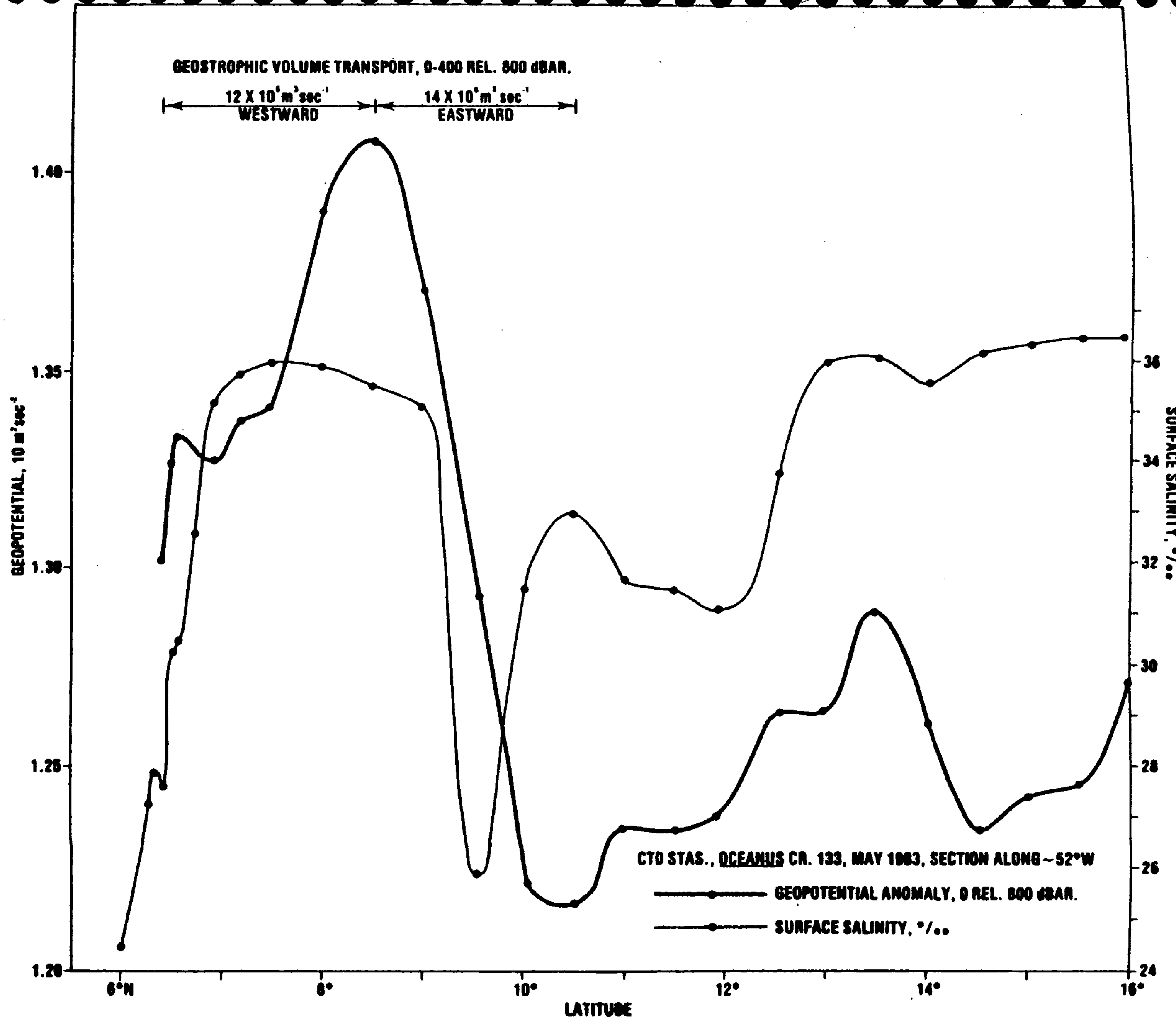

Figure 4. Geopotential anomaly, $10\,m^2\,s^{-2}$, and surface salinity, °/₀₀, from *Oceanus*, May 1983 section along 52°W, through northern eddy.

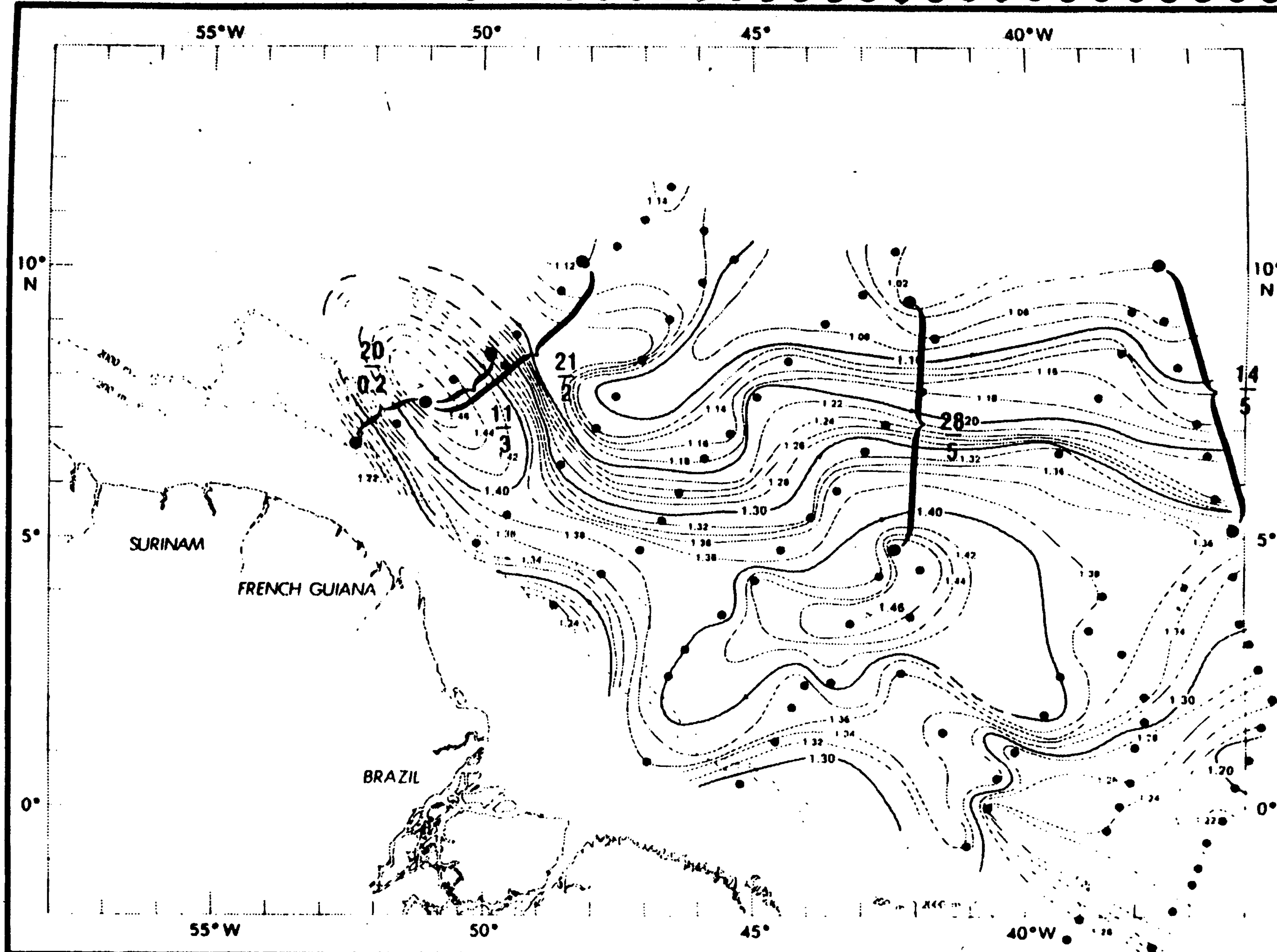

Figure 5. Geopotential anomaly, $10\ m^2\ s^{-2}$, 0/800 dbar, *Alaminos*, 31 July-10 September 1964. Volume transport, $10^6\ m^3\ s^{-1}$ (brackets), 0-150 dbar (upper value), and 150-400 dbar (lower value).

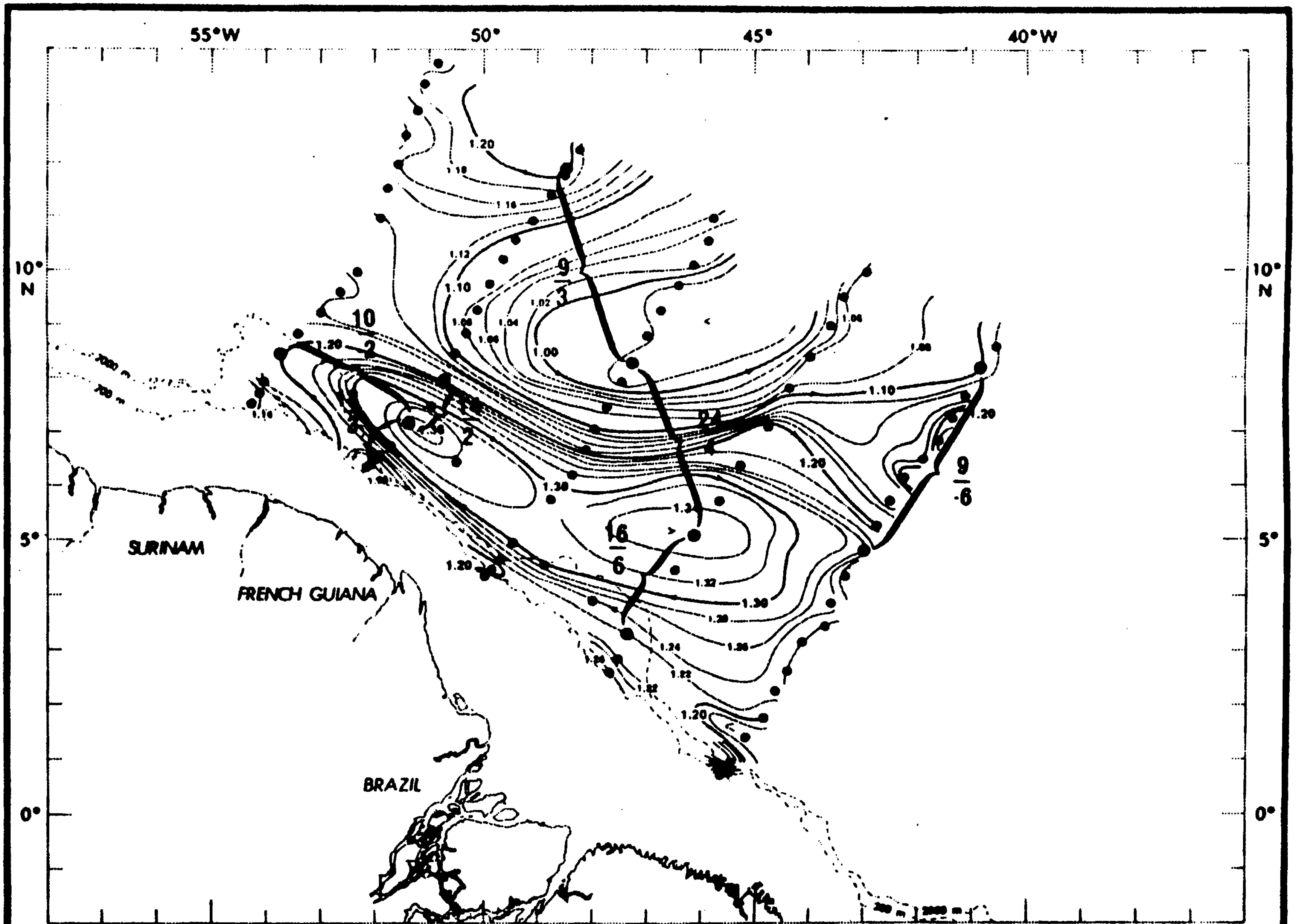

Figure 6. Geopotential anomaly, $10\ m^2\ s^{-2}$, 0/800 dbar, *Crawford*, 28 January-19 March 1968. Volume transport, $10^6\ m^3\ s^{-1}$ (brackets), 0-150 dbar (upper value), and 150-400 dbar (lower value) rel. 800 dbar. Positive value in direction indicated by bracket point.

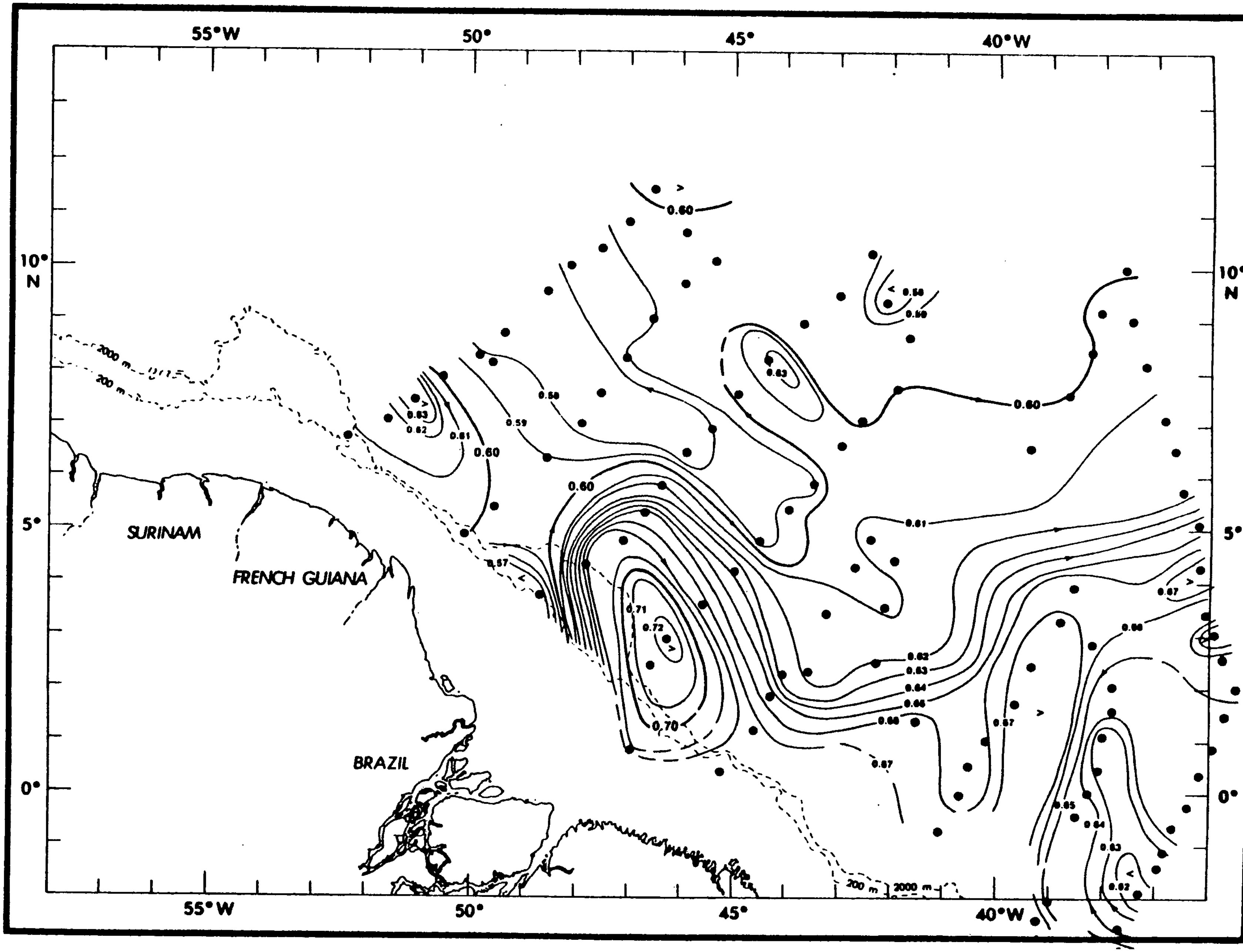

Figure 7. Geopotential anomaly, $10\,m^2\,s^{-2}$, 200/800 dbar, *Alaminos*, 31 July-10 September 1964.

SANDSTREAM ON THE NORTHEAST BRAZILIAN SHELF

MARCIO L. VIANNA
REYNALDO SOLEWICZ
ALEXANDRE P. CABRAL
Instituto de Pesquisas Espaciais

Preliminary characterization of transport on the northeast Brazilian continental shelf is attempted with a study of bedforms in a sandstream off Touros, 90 km north of the city of Natal. Sediment transport in this area is strongly influenced by the poorly known unidirectional North Brazil Coastal Current (NBCC) system, which includes the onshelf wind-driven current. Investigations supported by Landsat Thematic Mapper (TM) data have revealed that the sandstream can be divided into three distinct zones: (a) an inner zone dominated by sediment resuspension, caused by wave-driven turbulence; (b) an intermediate zone dominated by longitudinal bedforms; (c) an outer zone dominated by large-scale transverse bedforms, limited by shore-parallel sandridges adjacent to an ancient shoreface at 20 m depth. Extensive field work was done on the outer zone. Echo-sounder profiling and surficial sediment sampling indicated that the large-scale flow-transverse bedforms are asymmetric sand waves (dunes) of medium quartz sand, with heights of 3-7 m. Investigations by scuba diving showed the presence of ripples and absence of benthic epifauna on the stoss sides, which is indicative of active bedload transport. Two lee faces and two troughs were studies *in situ*. Lee slope angle maxima around 30° were determined with an inclinometer, and the faces were both of avalanche type. Flow separation was observed as movements of suspended algae, which were slowly drifting in the troughs, in the opposite direction relative to the surface flow. Further observations revealed absence of ripples and presence of established benthic ecosystems in patchy distributions within the interdune areas. The nature of the encrusting bryozoa found on shells collected at these sites suggests that the abrasion due to sand transport is negligible there, which also indicates very slow rates of dune migration. This dune field is very similar to another one described from the southeast African continental shelf. An echo-sounder transect crossing the field of longitudinal features in the intermediate zone seen on the TM-images supports the interpretation that the features are current-generated and rules out the alternative interpretation that they are ancient transgressive beach ridges.

SATELLITE OBSERVATIONS OF THE NBC RETROFLECTION AND AMAZON WATER DISPERSAL

FRANK E. MULLER-KARGER
University of South Florida

Time series (1979-1986) of Coastal Zone Color Scanner (CZCS) images of the Western Atlantic and Caribbean Sea were examined to determine the dispersal pattern of the Amazon and Orinoco River discharge. The imagery revealed that between June and January the discharge of the Amazon is carried around a retroflection of the North Brazil Current (NBC) into the North Equatorial Countercurrent (NECC) (Muller-Karger et al., 1988). The low salinities observed during this period in the eastern Caribbean as far north as Puerto Rico (Froelich et al., 1978) are caused by the dispersal of the Orinoco, rather than the Amazon (Muller-Karger et al., in press). Amazon water first goes eastward in the NECC, then returns westward in the North Equatorial Current, although some may reach Africa. Amazon water discharged during this period may drift for a few months to a year before potentially reaching the Caribbean.

From about February to May, the NECC west of 20° W reverses, the countercurrent and retroflection weaken or vanish, and the Amazon water drifts northwestward with the Guyana Current. At this time of year, Amazon River water enters the Caribbean more directly and on a time scale of a month. However, both Amazon and Orinoco waters tend to remain in the southern Caribbean (south of 14°N) due to a larger influx of north Atlantic water into the Caribbean forced by stronger trade winds.

High concentrations of phytoplankton often observed far offshore to the northeast of the Amazon's mouth are associated with the Amazon's plume. These high standing crops are produced initially by the nutrient supply in the Amazon River water and upwelling shoreward of the NBC retroflection. They are probably maintained by internal recycling and are slowly lost by sedimentation. The higher phytoplankton densities in the dispersed plume probably are the cause for a greater particulate flux from the surface layer of the tropical Atlantic compared to the tropical Pacific (see Deuser et al., 1988). We expect a similar signal offshore in the eastern/central Caribbean, but with the particulate flux at depth (>3000 m) showing a better-defined annual cycle.

Acknowledgements

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TOPSUB – A MULTIDISCIPLINARY STUDY OF THE SHAPING OF THE SEA FLOOR BY OCEAN CURRENTS AND THE IMPACT OF TOPOGRAPHIC INTERACTIONS ON CIRCULATION OVER THE N-NE BRAZILIAN CONTINENTAL SHELF

MARCIO L. VIANNA
Laboratório de Pesquisas Atmosféricas e Oceanicas
Instituto de Pesquisas Espaciais

The surface sediments over the low-latitude shallow N-NE continental shelf between the bifurcation of the South Equatorial Current and the mouth of the Amazon have been largely redistributed by the influence of tidal currents and the unidirectional North Brazil Coastal Current (NBCC) system, which operated on a transgressive sealevel trend. Due to the intense economic activity on this shelf, which includes an important lobster fishery and the exploitation of hydrocarbons, the mapping and understanding of all aspects of shelf dynamics in this area is essential.

Project TOPSUB (TOPografia SUBmarina e Dinâmica Sedimentar Quaternária), is a proposal designed to achieve the following technical and scientific objectives in a five-year time-frame:

- *Survey Work*:

  1. mapping and classification of topographic and ecosystem structures by use of satellite-image-assisted field work, which includes sediment sampling and diver observations, especially of sediment transport;

2. determination of "sub-grid" effects of bedforms on meso-scale ocean circulation;
3. analysis of bi-annual time-series of oceanographic variables obtained from moorings;
4. multi-satellite, multi-temporal image analysis to estimate advective velocities and wave parameters to be correlated with field measurements obtained from moorings.

- *Math Modelling*:

1. development of a new generation of circulation models using boundary elements which includes the influence of kilometer-scale topography on meso- scale circulation;
2. development of morphogenetic models (incorporating bottom sediment transport) which are capable of predicting bathymetric time-series.

At present, the following institutions are already participating on the proposal: INPE, PETROBRAS, UFF, FUNCEME, LABOMAR/UFCe.

The feasibility of such a program has been tested during the last two years, and preliminary reports on first results both on survey work and boundary element modelling are being presented in this workshop.

THE EQUATORIAL ATLANTIC CIRCULATION ACCORDING TO THE CME

MANUEL FIADEIRO
National Center for Atmospheric Research

Numerical models provide a wealth of detail and information that we cannot hope to match with observations. As such, they provide a framework to interpret data, plan cruises, and interpolate between observations–providing the model simulates reasonably well the actual conditions.

The community model experiment (CME) uses the GFDL primitive equation model of Bryan and Cox forced by monthly winds (from Hallerman and Rosenstein, 1983), surface heat fluxes and surface salinities in a domain covering the Atlantic Ocean from 15°S to 65°N. The vertical resolution ranges from 35 m at the top layer to 250 m at 1000 m and below. Frank Bryan ran a 25-year experiment at $\frac{1}{3}^\circ$ resolution last year, and this year he and I ran a 40-year experiment at 1° resolution. I will present some of the results of these simulations, focusing on the characteristics of the north equatorial circulation off the coast of Brazil.

The model simulates well the gross features of circulation, including the retroflection of the NECC during the summer and fall months. The most significant aspects of the circulation, according to the model, are:

- During the winter months, from January to May, the surface flow is towards the north and west. The NBC flows into the Guiana Current and into the Caribbean. The thermocline is flat in the north-south direction, and the Equatorial Undercurrent (EU) is shallow and slightly north of the equator.

- By the end of May the NBC continues to flow into the Guiana Current, and the EU intensifies by receiving water from the southern branch of the subtropical gyre. As the ITCZ moves north, it creates a zone of convergence around 5°N where the water moves eastward. Part of the NBC retroflects into this zone, which is the beginning of the NECC, although at this point it has not yet a separate identity, but is coupled with the EU.

- At the end of August the retroflection of the NBC is fully established. The Guiana Current is fed by the southern branch of the subtropical gyre. The EU and the NECC are separate entities. On the horizontal plane, the surface water flows clockwise around a high pressure center around 5°N. On the vertical plane, the water upwells and diverges at the equator, downwells on the south flank of the NECC, and returns to the equator in the subsurface layer. This "rolling" of the water in the vertical plane deepens the thermocline, which forms a valley at 5°N. The EU also deepens and moves to the equator.

- These conditions continue through fall, with progressive weakening of the NECC as the ITCZ moves south. The surface convergence zone vanishes and the zone of divergent equatorial upwelling spreads north and south. The thermocline goes up and flattens. The NBC joins the Guiana Current.

The $\frac{1}{3}^{\circ}$ resolution solution shows in even more detail the surface-subsurface circulation between the Equatorial Current and NECC. Since this is an eddy resolving model, the Legeckis waves generated in the NECC are clearly seen in the solutions. The circulation described above breaks in smaller loops, each wave carrying its loop with water flowing north and up on the crests, south and down on the troughs.

To finish, I would just comment that if the amazing structures created in the model–cyclonic and anticyclonic eddies, currents and countercurrents continually changing in space and time–are anything resembling the reality, it will be very difficult to make sense of only a few sparse current meters deployed along the coast of northern Brazil.

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THE STRUCTURE OF CURRENTS IN THE WESTERN TROPICAL ATLANTIC OCEAN

WENDELL S. BROWN
University of New Hampshire

The circulation in the western equatorial Atlantic is dominated by the seasonal retroflection of an intense western boundary current known as the North Brazil Current (NBC). During much of each year, the NBC is known to feed the North Equatorial Countercurrent (NECC) via pathways through the Demerrara (8°N) and Amazon (5°N) Eddies. The volume of the NBC, which escapes to northern latitudes, is unknown. This complex current system and the underlying flows of Antarctic Intermediate Water and North Atlantic Deep Water are believed to play a central role in the net northward heat transport in the Atlantic. A joint NSF/NOAA-supported study of the seasonal changes in the velocity structure over this large-scale region in the western tropical Atlantic will be conducted in 1990 and 1991. Pegasus current profile observations will be complemented by shipboard and moored current observations. A combined Pegasus, CTD/O_2, XBT and Acoustic Doppler Current Profile survey will be conducted four times between January 1990 and February 1992 (Figure 1). The overall study will incorporate moored current measurements by NOAA, Keil University, and ORSTOM (French) and inverted echo sounder measurements by Lamont in the interpretation of the four seasonal survey results. The overall study will provide the first direct measurements of the structure, transport, and seasonal variability of the NBC, the deeper western boundary currents and their connections to the equatorial and subtropical Atlantic flow fields.

TROPICAL WESTERN ATLANTIC

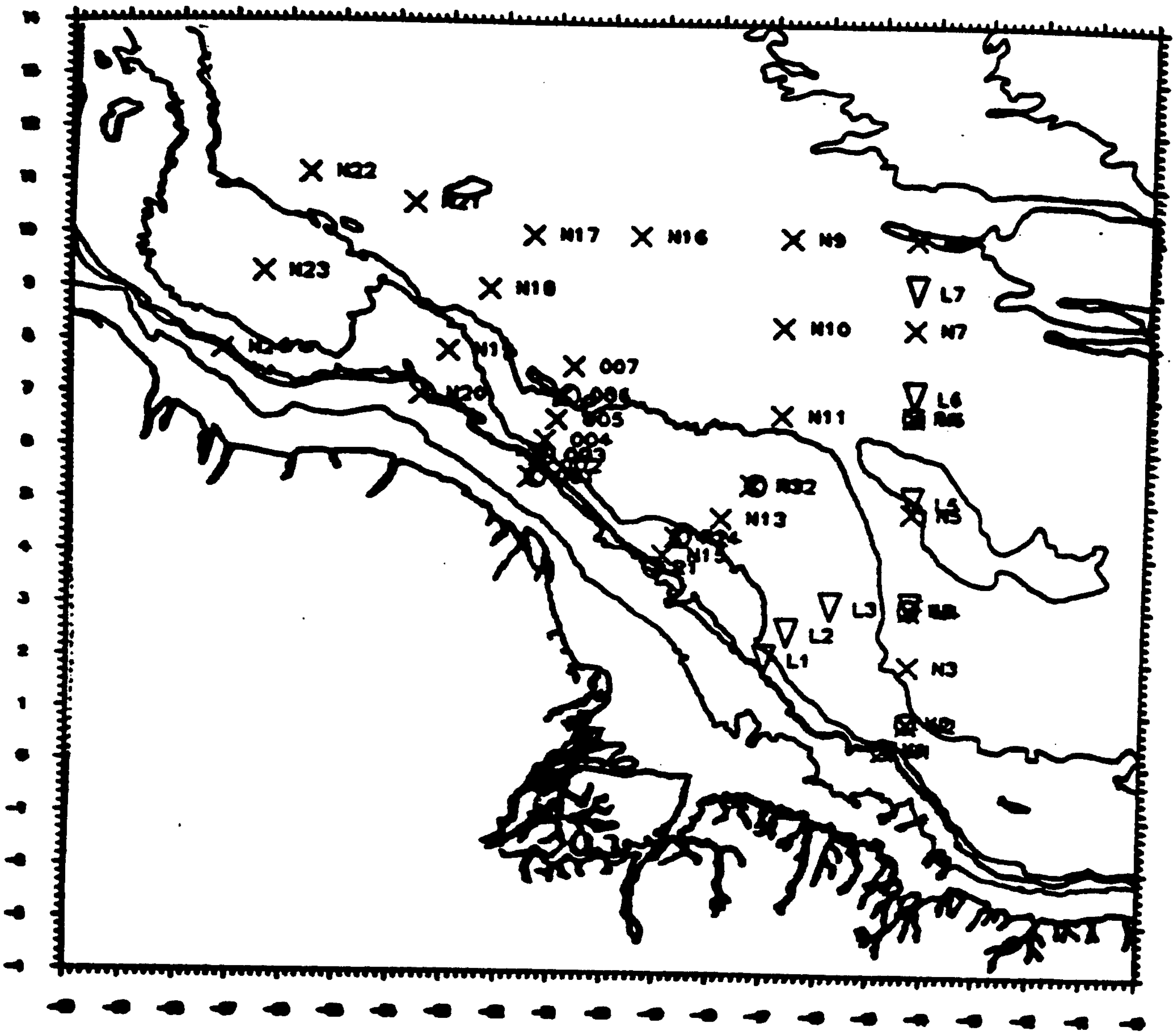

Figure 1. Combined moored array for making Pegasus current profiles (cross), current meter (circle), and inverted echo sounder (triangle) measurements. *N* refers to UNH/NOAA measurements, *K* to Keil, *R* to UM/NOAA, *O* and *OO* to ORSTOM, and *L* to Lamont.

LOW FREQUENCY VARIABILITY AND WAVE SCATTERING OFF ABRUPT TOPOGRAPHY: IMPLICATIONS FOR WESTERN BOUNDARY CURRENTS

KEVIN D. LEAMAN
Rosenstiel School of Marine and Atmospheric Science
University of Miami

Several years of observations in the western boundary currents at 26.5°N have illuminated certain remarkable features of both the mean and time-varying parts of these currents. Although we will refer on occasion to the whole water column, we wish to call attention in particular to the deep (below 800m) flow.

First, the southward transport in the Deep Western Boundary Current (DWBC) below 800 m is surprisingly strong at this latitude–the mean absolute transport determined from 11 Pegasus current profiler sections between April 1985 and September 1987 amounts to about 35 $\times$ 10^6 m^3 s^{-1} (35 Sv), $\pm$15 Sv, or about 2-3 times previously accepted values for this current.

Second, calculation of the southward transport in two freon-tracer "cores" associated with northern sources (Subpolar Mode Water and Norwegian Sea-Denmark Straits Overflow Water) indicates that only about 8 Sv of this transport can be accounted for by the thermohaline-driven component of the circulation.

The remainder (about 27 Sv) must reside in the horizontal field of the deep recirculation. However, in contrast to deep recirculation gyres further north (e.g., under the Gulf Stream), where vertical eddy momentum fluxes might at least provide a plausible driving force, similar strong currents are not present to the east of the Blake Plateau. Furthermore, the horizontal extent of this deep recirculation gyre is at present unknown.

On the other hand, significant energy is present at periods other than the mean; at this location the strongest peak is at about 100 days. The vertical and horizontal (eastward from the Blake Escarpment) structure of this peak suggests (in particular since the above period is shorter than the cutoff period for even the lowest baroclinic wave mode) that baroclinic waves are trapped along the Blake Escarpment (and extend roughly 50-70 km offshore). Results of a simple analytic model tend to confirm some features seen in the data. We speculate that these waves could drive a component of the deep mean flow.

In contrast to this region, observations of absolute currents in the DWBC off the northeastern coast of South America are very sparse. Limited current meter and Pegasus observations suggest that during at least part of the year, deep (below 2500 m) flow to the southeast can be as strong (20-30 cm s^{-1}) as has been observed further north. Also, some tracer (freon) data support the idea that at least part of the upper freon core leaves the coast and flows eastward, particularly at the equator. However, compared to 26.5°N, the deep flow here appears to be significantly less energetic relative to flow in the highly variable

surface layers. This may partly be due to differences in topography.

In January, 1989, we will deploy a grid of Pegasus current profiler stations along the continental boundary between 10°N and the equator to document the surface and deep flows in greater detail. Since this grid will remain alive for several years, we encourage active participation by others in its use.

APPLICATIONS OF THE INVERTED ECHO SOUNDER DEPLOYED IN THE WESTERN EQUATORIAL ATLANTIC

ELI JOEL KATZ
Lamont Doherty Geological Observatory

Inverted echo sounders have been continuously deployed in the western equatorial Atlantic since February 1983 at various sites. The longest data set presently available is across the North Equatorial Countercurrent along 38°W, or near upstream conditions. This allows for an estimate of the interannual variation of dynamic height across the NECC. This longitude and other sites with shorter time series are compared to the slope computed from a reduced gravity model using the monthly ship-derived winds, and we find that the ocean is more variable than the wind field (or model) suggests. Under the same assumptions of the model, the geostrophic transport is also computed and zonal changes indicated. While continuing the monitoring program (along 44°W), we now plan to attempt the same across the North Brazil Current.

A MODEL COMPARISON OF WINTER CIRCULATION DYNAMICS OF THE SAB (U.S.A.) AND SBB (BRAZIL)

JOÃO A. LORENZZETTI
JOSÉ L. STECH
Instituto de Pesquisas Espaciais

The southeastern coasts of Brazil (22°00'–28°37'S; 41°00'–48°49'W) and of the U.S. (24°00'–35°00'N; 80°00'–76°00'W) show several similarities in terms of form, length, and being both subject to the influence of western boundary currents over their shelf break regions. These two western boundary continental shelves are located in different hemispheres and in subtropical latitudes. Numerical experiments using a barotropic finite element model was conducted to make a comparative study of the wintertime circulation dynamics of these two regions. The analysis of the results of these experiments permitted the determination of the dynamic time of adjustment of these regions, and the momentum and vorticity balances. These results were utilized to compare the similarities and differences of the dynamics of both regions.

HYDROGRAPHY AND VOLUME TRANSPORT ON THE EASTERN BRAZILIAN COAST

LUIZ BRUNER DE MIRANDA
Instituto Oceanográfico
Universidade de São Paulo

Oceanographic work based on temperature measurements with XBT probes and hydrographic stations was conducted off the eastern Brazilian coast between 19° and 25°S, in order to obtain the spatial characteristics of the thermal structure and to locate the Brazil Current flow north and south of the Abrolhos region located at 20°30'S (Fig. 1). Although some results of this investigation have been previously published by Evans and Signorini (1985), the geostrophic velocity computations and the associated volume transports add some knowledge on the circulation of this region.

The salinity has been indirectly estimated from the XBT data by means of a polynomial fit of the T-S curves (Fig. 2), based on the hydrographic data obtained on the north and south sections.

The current structure and volume transport, relative to the 500dbar isobaric surface, has been computed using both hydrographic station data and the closely spaced XBT measurements. A comparison of these results for the section off Cabo Frio indicates that some details of the geostrophic currents are lost when the hydrographic data is used (Fig. 3); the volume transports for these data agree within 17% (3.3 Sv against 2.8 Sv, using hydrographic and XBT data, respectively).

A volume transport budget, estimated through the transport computations along all sections between 19° and 22°S, indicates that the Brazil Current appears to flow through the passage between the most inshore banks. The net volume transport of 2.9 Sv is in close agreement with the corresponding value of the Cabo Frio section (3.3 Sv), where the total flow of the Brazil Current was supposedly bracketed by the station sampling (Fig. 4).

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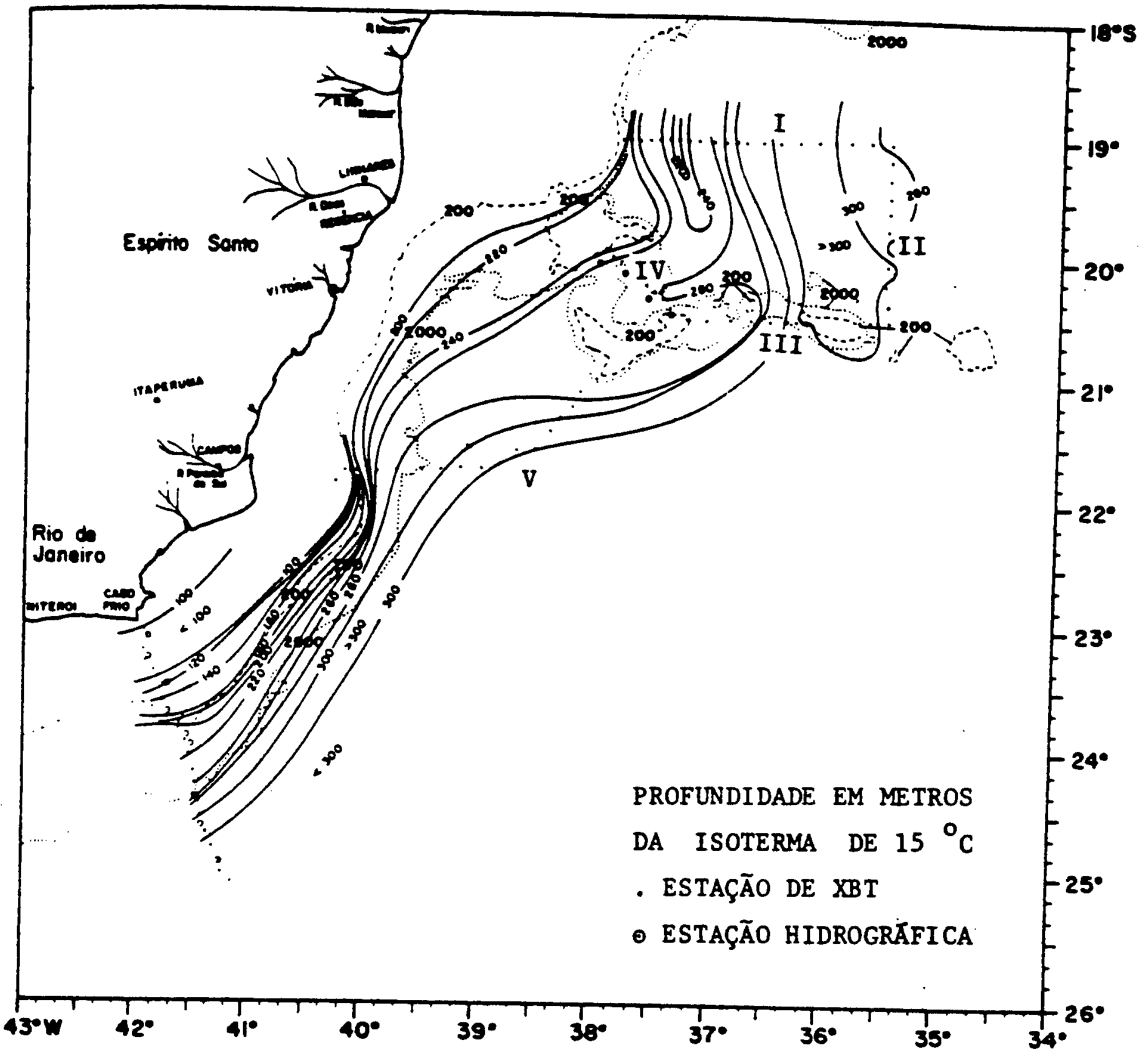

Figure 1. Location of XBT (·) and hydrographic (⊙) stations off the Brazilian east coast from 19° to 25°S.

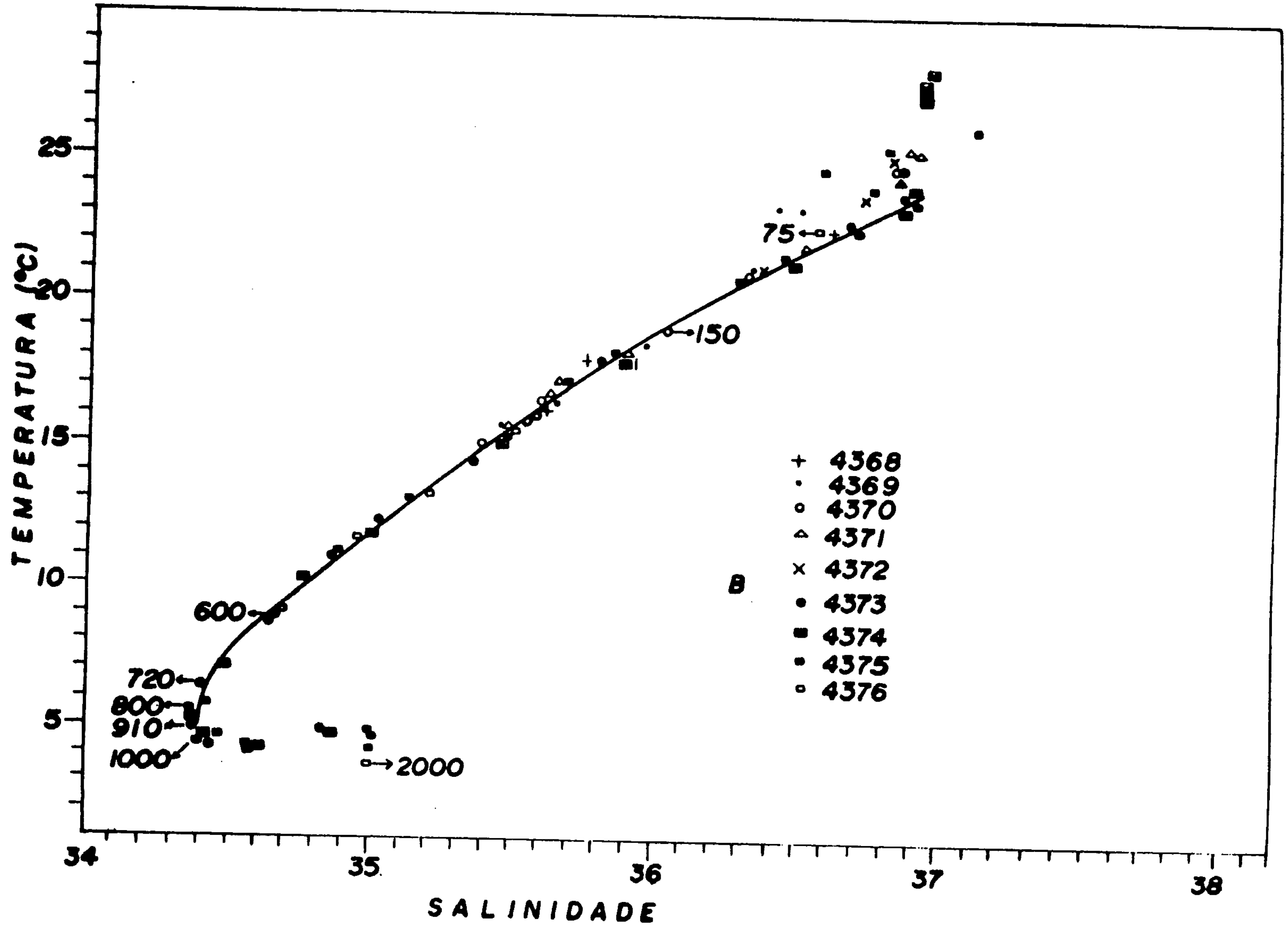

Figure 2. Salinity estimated by polynomial fit of T-S curves.

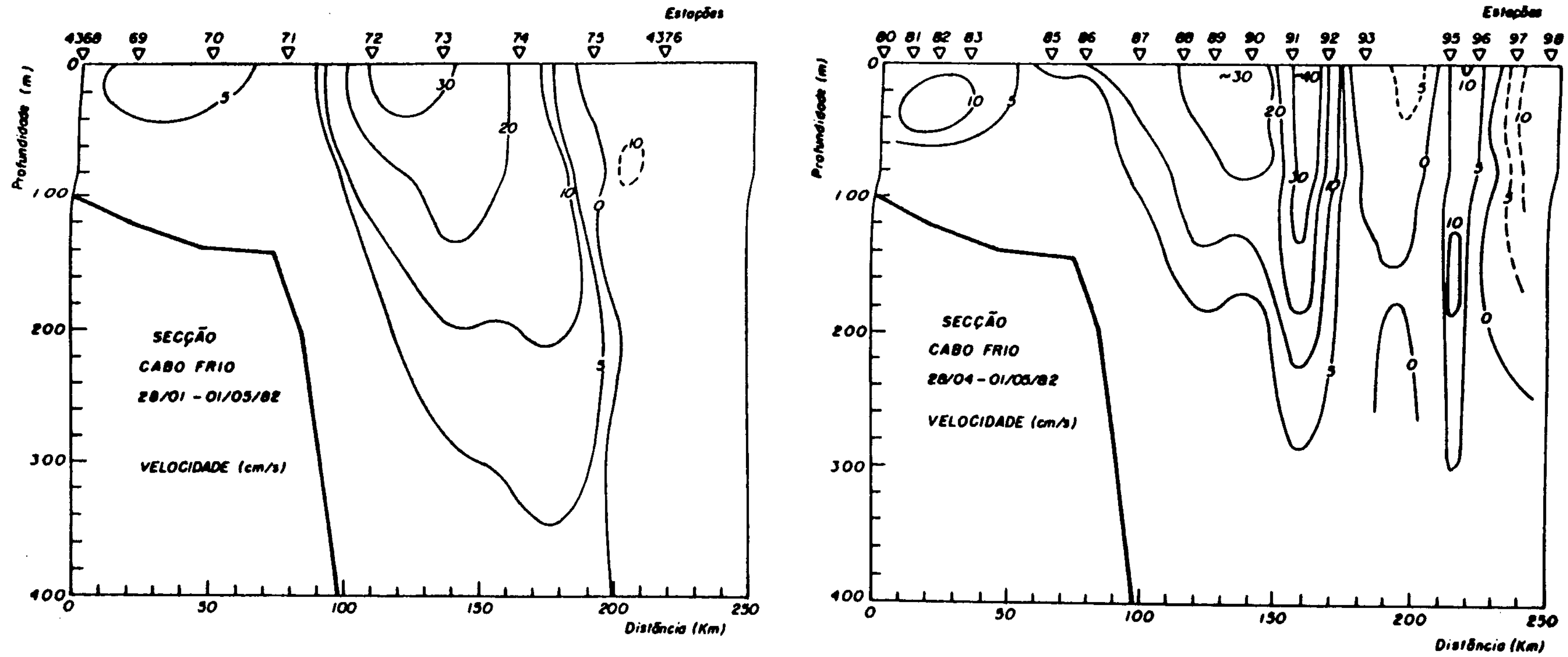

Figure 3. Current structure, relative to the 500 dbar isobaric surface, computed using (left) hydrographic data and (right) XBT measurements.

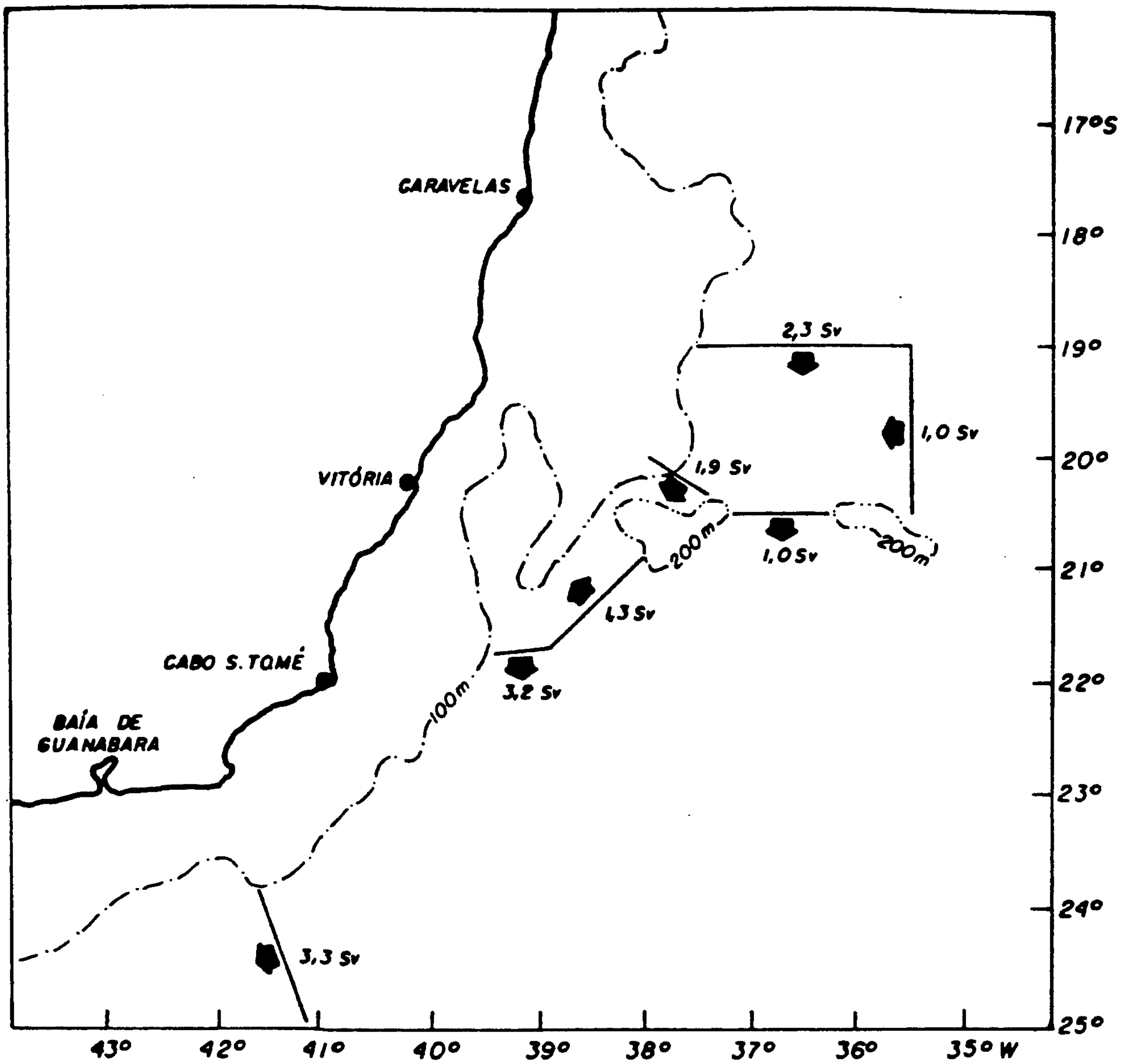

Figure 4. Estimated transports through the indicated sections in the Cabo Frio region.

BOUNDARY ELEMENT APPROACH TO OCEAN CIRCULATION MODELING

MARCIO L. VIANNA
PAULO R.C. HOLVORCEM
Instituto de Pesquisas Espaciais

The influence of complicated coastal geometries and boundary conditions on basin-wide ocean circulation is one of the major problems affecting most general ocean circulation models (GCMs). These problems are even worse when phenomena close to a western boundary have to be studied. We are introducing a new generation of GCMs which uses the so-called "boundary element methods." The great numerical advantage of these methods rests on the possibility of examining limited-area responses with high resolution, even if the forcing field over the basin is described by a standard grid. To better illustrate the method, a scheme for the solution of the linearized equatorial β-plane equations was developed. In this approach, the coastline has to be discretized into elements instead of the fluid domain. Thus, we reduce the dimensionality of the problem by one, and may obtain great spatial resolution with a small number of elements. Also, arbitrarily shaped coastlines can be more accurately described in this kind of numerical code than in finite difference schemes.

The governing equation for the pressure perturbation in a single vertical mode, at a fixed frequency, has the form:

$$L(\partial/\partial x,\, \partial/\partial y,\, y,\, \omega)\, p(\vec{r}) = F(\vec{r}), \tag{1}$$

where L is an elliptic operator with y-dependent coefficients, and F is related to the wind stress curl and divergence. To take into account the propagation of disturbances across the ocean, we define a Green's function for the adjoint operator L by the condition

$$L^{+} G(\vec{r};\vec{r}') = \delta(R), \quad \vec{R} = \vec{r} - \vec{r}'. \tag{2}$$

This function represents the pressure response at $\vec{r}$ due to a certain wind stress distribution which has a $1/|\vec{R}|$ singularity at the "source" $\vec{r} = \vec{r}'$. Analytic expressions for the Green's function may be given in terms of Hermite functions; the field G consists of a finite number of modes with westward (eastward) group velocity in the region to the west (east) of the source $\vec{r}'$, and of an infinite number of modes of complex wavenumber trapped near the source's longitude. The superposition of these modes to make up the total field G is complicated, but we have developed asymptotic methods to evaluate this sum accurately and efficiently.

Multiplication of (1) by the complex conjugate of G, integration by parts over the ocean region B, and application of the slip boundary condition at the coast Γ will yield our fundamental boundary integral equation:

$$\alpha p(\vec{r}') - \oint_\Gamma ds\, p(\vec{r})\, \hat{n}(\vec{r})\, \vec{K}(\vec{r}'; \vec{r}) + \int\int_B dx dy\, \vec{\tau}(\vec{r}) K(\vec{r}'; \vec{r}) = 0. \qquad (3)$$

Here, the kernel $\vec{K}$ is related to the gradient of G, $\hat{n}$ is the outer normal to the fluid, $\vec{\tau}$ is the wind stress, and the constant α is 1 if $\vec{r}'$ is an interior point of B, and $\frac{1}{2}$ if $\vec{r}'$ is on the boundary Γ.

In numerical applications, the point $\vec{r}'$ is first assumed to be located on the boundary. Then (3) will involve only unknown boundary values of p and the prescribed forcing over the ocean. The integral equation is discretized along the coast using boundary elements, and numerical quadrature is used to evaluate the forcing term. Once the boundary values are known, (3) is used as an integral representation of the interior solution at an arbitrary point $\vec{r}'$ in the interior of the fluid, thus generating the sought-for fields of pressure, velocity and density perturbations.

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ESTIMATES OF THE ZONAL SLOPE AND SEASONAL TRANSPORT OF THE ATLANTIC NORTH EQUATORIAL COUNTERCURRENT

James A. Carton
University of Maryland

Eli Joel Katz
Lamont Doherty Geological Observatory

We use data from six inverted echo sounder moorings and the GEOSAT satellite altimeter to examine the seasonal variability of sea surface elevation. Monthly sea level maps are constructed using subsurface temperature data to provide a reference sea level field. The maps are then used to describe the origin and structure of the western tropical Atlantic North Equatorial Countercurrent during a two-year period beginning November 1987. The data reveal a zonal current which is confined between 3°N and 9°N with a typical width of 300 km. The NECC flows strongly eastward during November and December 1986, and May 1987 through January 1988. The reappearance of the current is then delayed until the end of our record in October 1988.

Volume transport is estimated for the two-year period from surface elevation by approximating the vertical structure of the ocean as a two-layer fluid. We find that the NECC has a maximum transport of 40 Sv at 38°W. This water has its origin in the retroflection of the North Brazil Current. Eastward of 38°W, the NECC loses strength as water exits the current to join the currents farther south.

NUMERICAL SIMULATION OF A RESPONSE OF AN OCEANIC FRONT TO A MESOSCALE ATMOSPHERIC FORCING

CLAUDIO SOLANO PEREIRA
Instituto de Pesquisas Espaciais

AFFONSO DA SILVEIRA MASCARENHAS, JR.
Instituto Oceanográfico
Universidade de São Paulo

The influence of middle-latitude cyclones and their associated cold fronts on open-ocean fronts is studied with the approach of numerical simulation. An embedded mixed-layer ocean circulation model is developed analogous to that of Adamec et al. (1981). Finite differences with horizontal resolution of 5 km in a staggered grid are used to solve the model equations within a domain of total meridional extension of 300 km and 500 m depth. Two numerical experiments were performed to investigate the response of an ocean front, similar to the South Atlantic subtropical convergence zone, to a mesoscale atmospheric forcing (cold front). Under the effect of the cold air outbreak, the thermal and dynamic structures of the upper layers are substantially modified with a more intense sinking/cooling rate of the mixed layer. The sinking/cooling rate depends strongly on the magnitude of the thermal gradient at the thermocline top and on the mixed-layer depth. Due to the different sinking/cooling rates, a single storm can move the oceanic front up to 20 km from its initial position.

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IS THE SVERDRUP RELATION VALID IN THE SOUTH ATLANTIC?

AFFONSO DA S. MASCARENHAS, JR.
OLGA T. SATO
Instituto Oceanográfico
Universidade de São Paulo

Assuming a linear and baroclinic model in steady state, and neglecting the lateral diffusion of momentum, the potential vorticity balance is given by the planetary vorticity and the vortex tube stretching/compression. These assumptions lead to the physical mechanism conventionally called the "Sverdrup relation" or "balance." Hellerman and Rosenstein wind stress data were used to compute monthly and annual means in $1^\circ \times 1^\circ$ squares of the horizontal field, the wind stress curl and the mass transport stream function between 5°N and 35°S latitude. Zonal oceanographic sections across the South Atlantic, based on measurements of temperature, salinity/conductivity, and depth/pressure, were used to compute the mass transport of the ocean. Two methods of determining the level of no motion are discussed. The estimates of the transport in the center of the gyres suggest that the Sverdrup relation can be valid. The mass transport maps show a region of zero transport, frequently in the NW-SE direction. Such evidence suggests a pattern of two assymmetric surface gyres–a result that contradicts our present understanding.

BUOY-BASED MET-OCEAN DATA ACQUISITION SYSTEM DEVELOPMENT AT INPE

PEDRO RUBENS DE CARVALHO
MERRITT RAYMOND STEVENSON
CARLOS LEANDRO DA SILVA, JR.
Laboratório de Pesquisas Atmosféricas e Oceanicas
Instituto de Pesquisas Espaciais

A growth of the demand for Met-Ocean buoys from various organizations in Brazil is causing an expansion in the interests of INPE's Drift Buoy Research Group, previously dedicated to the development of rugged drift buoys to be deployed in Antarctica. Some of INPE's concepts for the development of multi-task, satellite-interrogating, moored buoys for use by Petrobras on slope waters will be presented.

TOWARDS A CAPABILITY OF MAPPING SEA SURFACE PARAMETER FIELDS BY AIRBORNE MICROWAVE RADIOMETERS

ULF PALME
Instituto de Pesquisas Espaciais

Microwave measurements of sea surface temperature and salinity by airborne sensors have been reported in the past as suffering from problems of low resolution. On the other hand, the efficient mapping of oil slicks by airborne microwave radiometers has been proven. In order to further develop techniques of obtaining higher resolution, a research program is being started to measure the Debye parameters of samples of saline water, using time-domain reflectometry techniques (TDR) up to 10 GHz in a joint effort between INPE and Instituto Mauá de Tecnologia (IMT).

VARIABILITY OF THE NORTH BRAZIL CURRENT AND NORTH EQUATORIAL COUNTERCURRENT OFF FRENCH GUIANA: 1987-1988

WILLIAM E. JOHNS
Rosenstiel School of Marine and Atmospheric Science
University of Miami

Advances in tropical oceanography over the past few decades have led to the realization that low latitude western boundary currents play an important role in cross-equatorial mass transport and recirculation of water within the zonal equatorial current systems. In the Atlantic, observations have shown that an intense North Brazil Current (NBC) along the coast of South America carries water northward from the South Equatorial Current, where it impinges on the east coast of Brazil. Presently there are few direct measurements of this current system, although observations by Flagg et al. (1986) in December 1980 showed the NBC to be 100-200 km wide, with northwestward flow extending to at least 500 m depth, and with a total volume transport near 2°N of approximately 50×10^6 m^3 s^{-1}.

Most of the northward transport of the NBC is thought to be returned to the ocean interior between the equator and about 8°N in a system of eastward flows at various levels. Water mass analyses by Metcalf (1968), Metcalf and Stalcup (1967), Cochrane (1969), and others suggest that the offshore flow from NBC to the ocean interior occurs at different depths at different latitudes, with: a) flow in the thermocline separating just north of the equator to feed the Equatorial Undercurrent, b) flow beneath the thermocline separating near 3°N to feed eastward subthermocline countercurrents, and c) flow near the surface separating near 6°N to feed the North Equatorial Countercurrent (NECC). The separation of surface layers of the NBC near 6°N during summer and fall is well documented in surface drifter trajectories (Richardson and Reverdin, 1987) and in Coastal Zone Color Scanner (CZCS) imagery (Muller-Karger et al., 1988), which show clearly the offshore advection of high-nutrient Amazon River water lying adjacent to the coast there. These observations also support the historical view that during the winter and spring, when the NECC is weak or absent, the NBC continues northward as a continuous near-surface flow along the coast into the Guiana Current and the Caribbean. This feature of the tropical Atlantic circulation is related to the northward mean transport of surface and thermocline waters required to balance southward cross-equatorial transport of cold water formed by deep convection in the North Atlantic. Both models (Stommel, 1957) and observations (Gordon, 1986) suggest that north of the equator in the Atlantic the deep southward transport and northward upper layer return flow are concentrated in the western boundary.

In 1986 the NOAA STACS (Subtropical Atlantic Climate Studies) program initiated a regular program of observations in the tropical Atlantic, consisting of

repeated shipboard hydrographic surveys, Pegasus direct velocity profiling, and moored current meter observations. Initial focus was on the region near 6-8°N off the coast of French Guiana, to investigate the dynamics of the NBC/NECC retroflection zone and to explore methods for monitoring the seasonal variation in northward throughflow of South Atlantic waters along the western boundary.

Results from an array of moored current meters deployed in the retroflection zone during 1987-88 are presented, showing that:

1. seasonal variations in upper level mean currents are large and generally consistent with previous observational and model results,
2. a strong, steady, deep western boundary current flows southeastward at the base of the continental rise with core speeds of nearly 0.3 m s^{-1},
3. low-frequency current fluctuations in this region are dominated by a sharply periodic 40-60 day oscillation that appears related to eddy generation from the NBC retroflection front.

Plans for future work in the western tropical Atlantic involving a cooperative international effort of U.S., Brazilian, German, and French scientists are also presented and discussed.

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REFLECTION OF EQUATORIAL WAVES FROM OCEANIC BOUNDARIES OF ARBITRARY SHAPE

PAULO R.C. HOLVORCEM
Instituto de Pesquisas Espaciais

A boundary element method is used to study numerically the reflection of equatorial waves from ocean boundaries of arbitrary geometry. The problem is formulated as an integral equation over the boundary, which relates the unknown pressure values on the boundary with the remote forcing represented by the incident wave (see Vianna and Holvorcem, this volume). The kernel of the integral equation includes all the possible modes of the equatorial plane, not just the long waves, which were the only modes retained in some previous studies. In this way we expect to treat more rigorously the fluid motion near the coast.

The boundary is divided into N short segments, and the discrete version of the integral equation is an $N \times N$ system of linear equations for the boundary pressures. Once this system is solved for the N boundary values, the pressure and velocity at any interior point can be computed by using the integral equation as an integral representation of the interior solution in terms of the boundary values. It is important to note that since the fluid domain is not divided into cells, the only limitation to the resolution comes, in principle, from the finite size of the boundary elements; however, the constraint is not as strong as that implied in "2 × noise," since it is known that integration is a smoothing process. The resulting interior field will always tend to be smooth because even the short wave modes are exactly included in the kernels of the integral equation.

Our calculations with the South American continental margin between 20°S and 20°N use $N = 56$ elements. Sample results (Fig. 1) show the total pressure perturbation at a given instant when the incident wave is the first Rossby mode with a period of 2.4 months. (In this case the Kelvin wave speed is $1.26\, m\, s^{-1}$.) There is a region of enhanced amplitude centered at 5°N, 43°W. The amplitude of oscillation of the reflected field is shown in Figure 2. The amplitude is modulated at a zonal scale of about 25°, and the spot of large amplitude is clearly seen. We speculate that the eddy with large thermocline depths found by Bruce and Kerling (1984) in the region of our large amplitude spot may be attributable to an effect of the coastal geometry on the wave field incident from the east. The current calculations (not shown) exhibit clearly vertices with zonal scales as small as 1°; in fact, we have not yet found an upper limit for the spatial resolution which can be attained with our discretization of the boundary.

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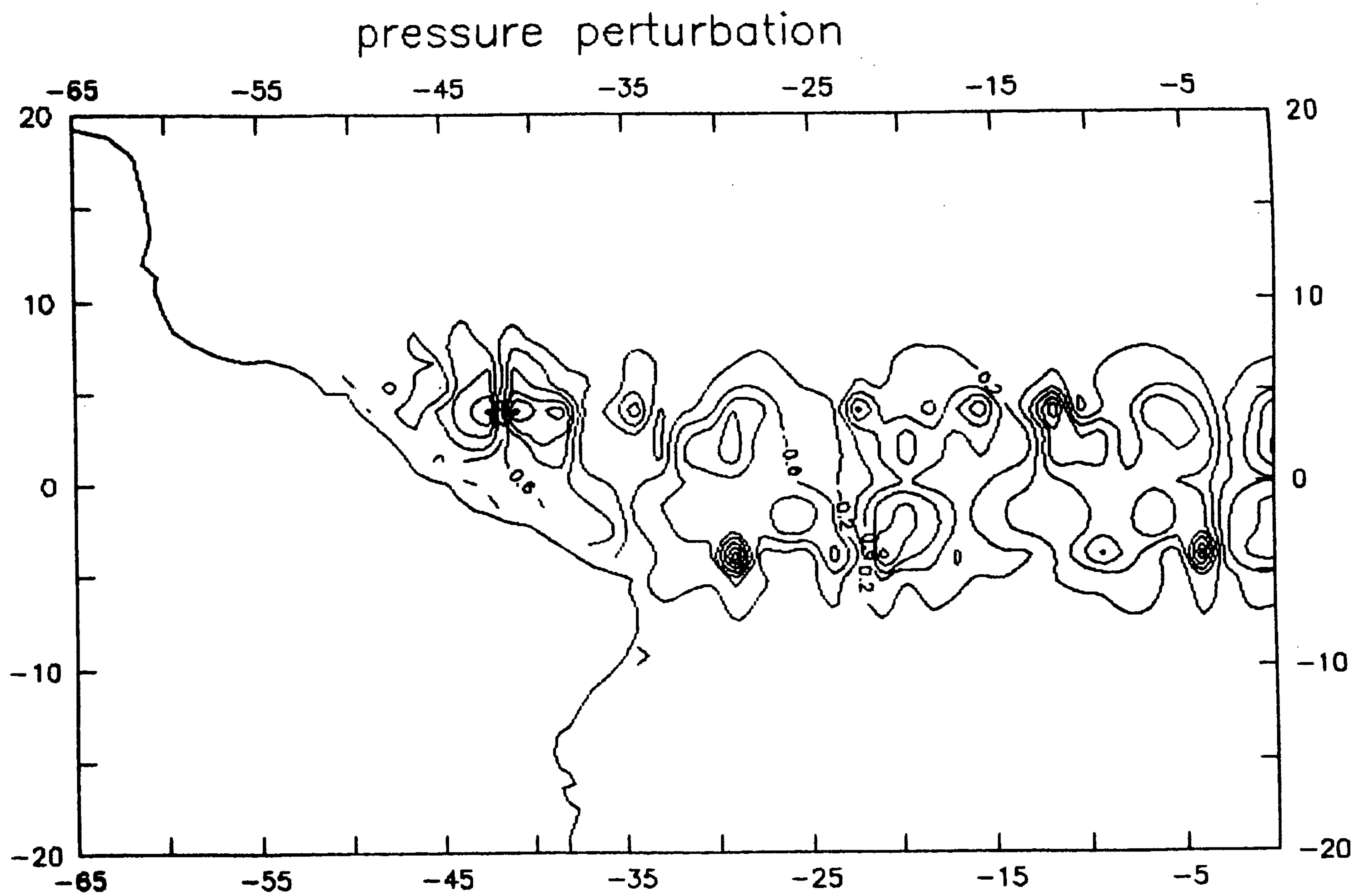

Figure 1. Total pressure perturbation associated with an incident Rossby wave (mode 1) with a period of 2.4 months.

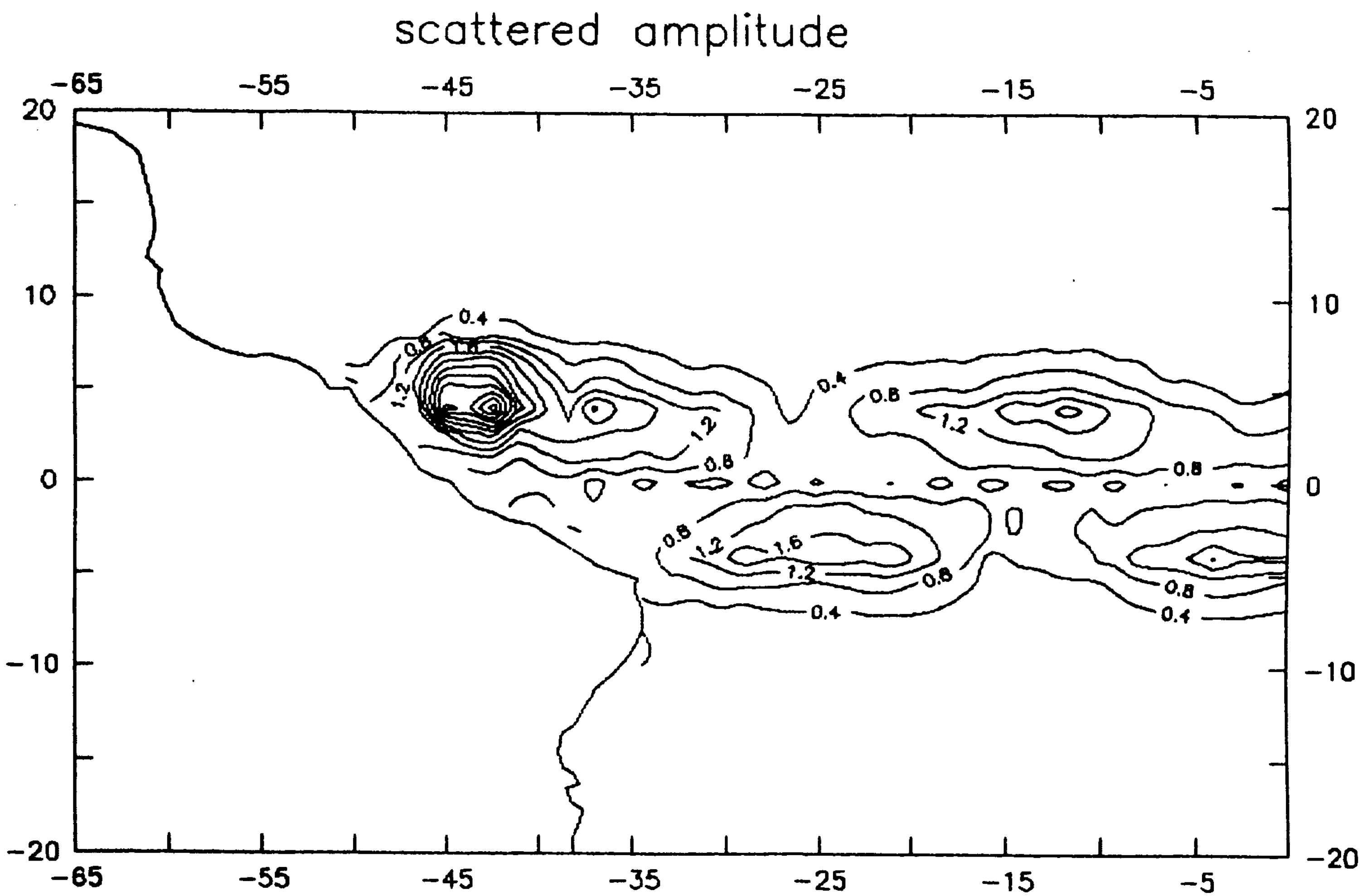

Figure 2. The amplitude of the reflected wave field due to the incident mode 1 Rossby wave in Figure 1.

STATIONARY ROSSBY WAVES IN WESTERN BOUNDARY CURRENT EXTENSIONS

E. Campos, D. Olson and D. Boudra
Rosenstiel School of Marine and Atmospheric Sciences
University of Miami

Results of numerical experiments with an Eddy Resolving General Circulation Model (EGCM), performed with the purpose of studying finite-amplitude Rossby waves superimposed on western boundary current extensions, are reported. These experiments focus on the effects of basin geometry, wind-stress distribution, and lateral boundary conditions on the existence, structure and dynamics of those features. Experiments with time-independent wind-stress distributions show that the western boundary orientation relative to the wind stress direction plays a decisive role in the existence of quasi-stationary pattern superimposed on the mid-latitude jet of two-gyre experiments.

This work is largely motivated by results of observations in the region of confluence of the Brazil and Malvinas Currents (e.g., Legeckis and Gordon, 1982; Roden, 1986; Olson et al., 1988). According to those observations, on the western side of the South Atlantic subtropical gyre, the Brazil Current flows southward to approximately 38°S, where it encounters the northward-flowing Malvinas Current. At this confluence both currents separate from the coast, with the Brazil Current continuing poleward before looping back to the north, forming a large extension of the South Atlantic thermocline water. The general pattern is that of a quasi-stationary wave with wavelength of about 400 km and amplitude of about 200 km (Fig. 1). Legeckis and Gordon (1982) report that the southern limit of this extension fluctuates within the region limited by the latitudes 38 and 46°S and the longitudes 50 and 56°W, with time periods as short as two months. Those oscillations are confirmed by Olson et al. (1988), who, in addition to 30-day and 60-day oscillations (possibly linked to the mesoscale eddy field), also report cyclical excursions of the currents along the coast at semi-annual and annual periods. Olson and his coworkers hypothesize that the quasi-stationary wavelike structure of the confluence region acts as an energy reservoir into which the Brazil/Malvinas Currents slowly impart energy. This energy is then periodically released back into the boundary as the wave train become transient. This is theoretically possible, and, according to Gordon (1988), such an event was possibly observed in January-February 1985. A study of the existence and dynamics of such phenomenon, in a numerical simulation, is among the goals of the current investigation.

Analytical calculations, using zonal mean flows with no spatial shears, show that free stationary Rossby waves with amplitude decaying in the x-direction are solutions for the nonlinear quasi-geostrophic vorticity equations with Laplacian lateral dissipation. For mean flow strengths comparable to those observed in the Brazil/Malvinas confluence, the wavelengths of these analytical solutions

are roughly similar to the observed waves. Due to the high degree of complexity of the real world, however, all attempts to obtain further information using analytical methods prove to be extremely difficult, if not impossible. Numerical approaches, while also approximations, constitute the most viable option for going a little further. The numerical experiments discussed here apply Bleck and Boudra's isopycnic coordinate model, and were designed according the following strategy. First, conditions for the existence of quasi-stationary features are investigated; and second, the dynamics and structure of these features are then analyzed. The numerical simulations have been carried out at the National Center for Atmospheric Research (NCAR) computer facilities (CRAY-XMP).

In order to assess the effects of north-south asymmetries and boundary conditions on the existence of stationary Rossby waves in the eastward extension of western boundary currents, experiments were performed using different western boundary geometry, boundary conditions, and location of the zero wind-stress curl. For perfectly symmetric conditions–that is, rectangular domain with zero wind-stress curl along the central latitude of the basin–the time-averaged circulation shows a perfectly zonal mid-latitude jet. As soon as north-south asymmetries are introduced, either by tilting the western boundary or by changing the latitude of the wind-stress curl, a stationary pattern starts to show up in the time-mean mid-latitude jet. For a western boundary geometry resembling that of the South American continental shelf from 20° to 55°S (not including the Malvinas Bank), the stationary wave train is similar to the one observed in the real world (Fig. 2). Phase diagrams along specific latitude lines for the streamfunction and eddy-kinetic energy reveal a quasi-stationary wavelike behavior, similar to what is observed in the Brazil/Malvinas extension. The transient behavior seems to be in accordance with the hypothesis of Olson et al. (1988). Kinetic energy builds up in a stationary pattern in the confluence region and, then, from time to time is released back towards the western boundary.

Although the analyses of the results are still in an early stage, preliminary results seem to indicate that the geometry of the western boundary plays a major role in the existence of the stationary wavelike pattern of the western boundary current extension. Also, it seems to be safe to conclude that the other constraints investigated–the boundary condition and stratification–affects only the structure and strength of those features.

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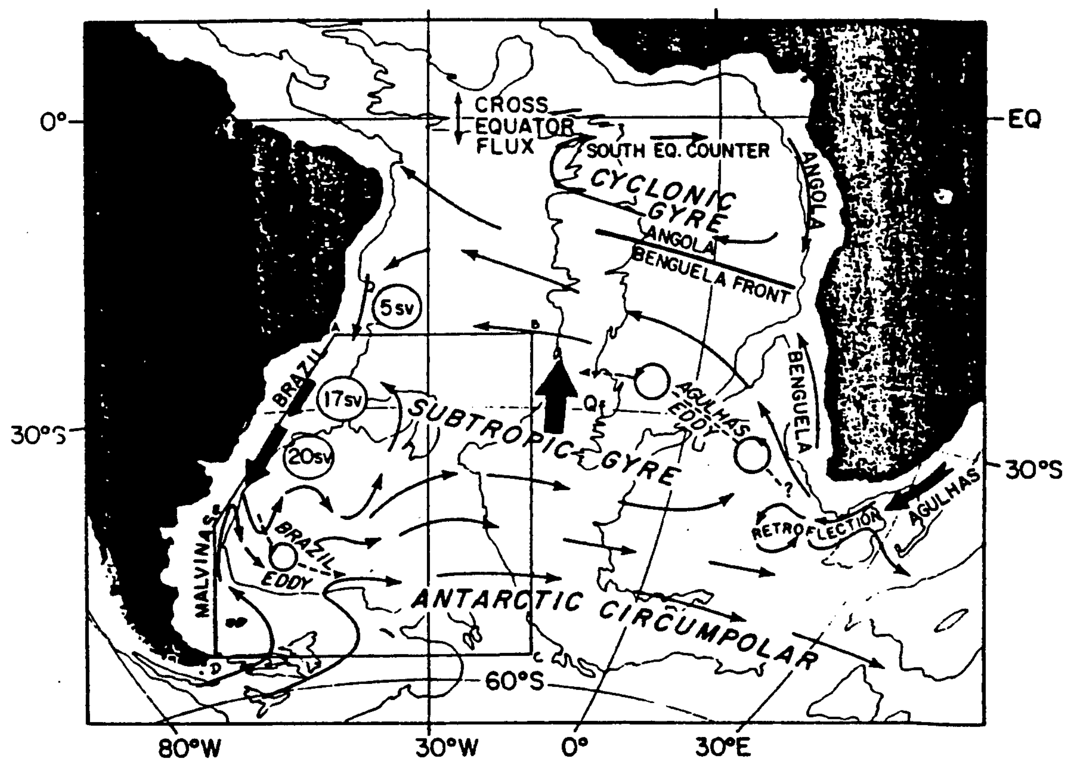

Figure 1. South Atlantic large scale mean circulation (Gordon, 1988). The numerical simulations were performed in the portion of the basin represented by the polygon ABCDE.

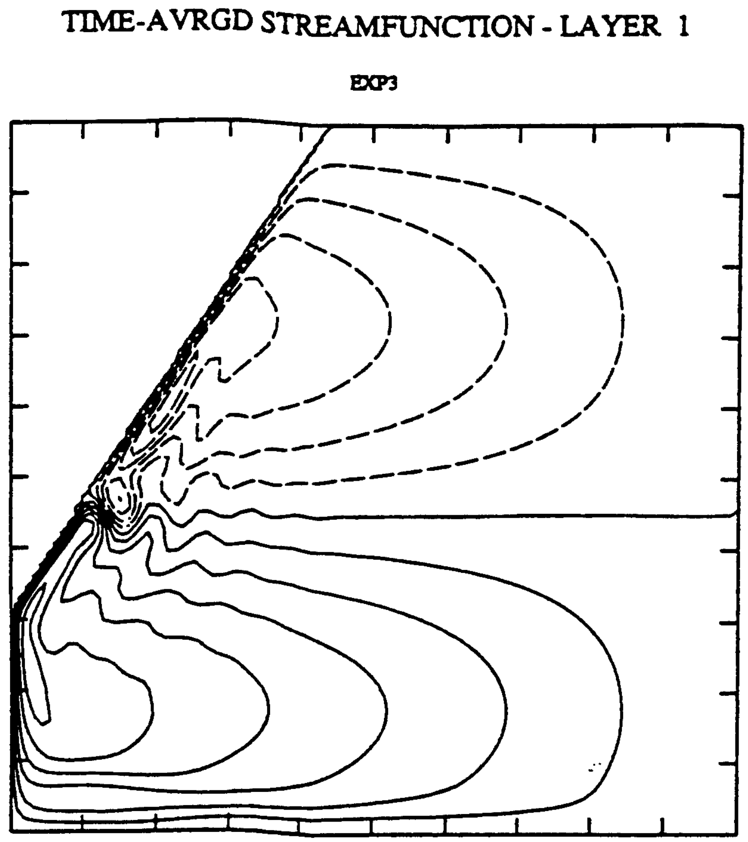

Figure 2. Upper layer mean circulation of a two-layer experiment using an approximation of South America coastline from 20° to 55°S.

DISPERSION PROCESSES OF THE SUSPENDED MATERIAL TRANSPORTED BY BARRA NORTE COASTAL WATER–AMAZON RIVER

Renato Herz
Instituto Oceanográfico
Universidade de São Paulo

LANDSAT, SPOT and NOAA platforms have led to a large expansion in the knowledge of the coastal processes related to the suspended solid material transport on the Brazilian continental shelf. From the systematic inspection of images from these satellites, an appreciable amount of understanding was gathered, helping to test some previous hypotheses established by means of surface sampling by field researchers. With this technique of the remote observation of natural phenomena, it is possible to establish, with a good degree of precision and synopticity, the spatial distribution of different suspended material concentration. The correlation of these data with the ones of the land support ascribe certain dynamical tendencies to the coastal waters. Much of this evidence enables oceanographic researchers to define the very complex details when MMS, and more recently TM and LANDSAT images are analyzed. The source areas and the mechanics of the mixing between the Amazon Basin fresh waters and the oceanic waters can be identified on the western equatorial Atlantic from these images.

III. DISCUSSIONS

INTRODUCTION

The technical presentations below outline the significant progress which has taken place since the last workshop, by Brazilian and U.S. researchers in both the Brazilian coastal and deep oceans. Shelf studies in the South Brazilian Bight by Castro (IOUSP) and Lorenzzetti (INPE) have begun to reveal the first order wind-driven response and hydrographic variability of the region. Lagoon studies in southern Brazil by Müller (FURG) have defined the basic physical processes responsible for the circulation. In the north, new observations have been obtained. These include new deep sea hydrographic and tide observations by Mesquita (IOUSP); deep sea currents and hydrography by STACS scientists Johns, Leaman, Lee (RSMAS) and Molinari (NOAA); sea level maps derived from satellite altimetry by Carton (UMD); shelf hydrography and surface currents by Limeburner, Beardsley and Geyer (WHOI); and model results by Vianna and Holvorcem (INPE).

These new results generated lively discussions on the best ways for U.S. and Brazilian physical oceanographers to collaborate in the future. The most promising avenues seem to include:

- An effort to deploy a current meter mooring at the 100m isobath between the offshore end of the AMASSEDS moored shelf array and the inshore end of the RSMAS/STACS moored deep ocean array. Castro (IOUSP) has committed three current meters for the planned February through June deployment. One additional current meter and the mooring hardware will be supplied by WHOI.

- A joint effort to model the tides in the region of the Amazon outflow by Lorenzzetti (INPE), Castro (IOUSP) and Beardsley (WHOI).

- A collaborative effort to make ocean color measurements in the region of the Amazon outflow, NBC retroflection, and the northeastern Brazilian Shelf. Vianna (INPE) has committed time and an INPE aircraft which will carry remote sensing instrumentation provided by Muller-Karger (USF) for these observations.

- Participation on the NSF/STACS Pegasus cruises by several Brazilian students. A number of these students are applying to U.S. institutions, including UMD and UNH, for Ph.D. degrees.

Discussions of longer time scale interactions included interest in:

- Using satellite imagery of Herz (IOUSP) to infer sediment dispersion patterns in support of AMASSEDS studies of the Amazon outflow.

- Joint synthesis of Brazilian and U.S. hydrography and tide measurements in the northeast of Brazil by Mesquites (IOUSP) and others.
- Joint modelling studies by Vianna and Halvorcem (INPE), Carton (UMD), Johns (UM) and Molinari (NOAA) on the dynamics of the western tropical Atlantic.
- Joint Pegasus/CTD studies of the Brazil Current by Johns/Leaman (UM) and Mascarenhas/Ikeda (IOUSP).

The following are more detailed accounts of the various discussions concerning Brazil/U.S. collaboration.

DISCUSSION OF THE AMASSEDS PROGRAM: PRESENT STATUS AND FUTURE POSSIBILITIES

R. Geyer

AMASSEDS is an interdisciplinary study of physical, geological and chemical processes in the Amazon disperal system (the continental shelf where sediment is transported and deposited). The physical oceanographic component focuses on frontal dynamics, interaction of the North Brazil Current with the outflow, and the boundary layer processes influencing the sediment dispersal.

Schedule

Cruise 1	July '89 (completed)
Cruise 2	Feb-Mar '90
Cruise 3	June-July '90
Cruise 4	Oct-Nov '91

Details of Cruise 2

	1/25-2/5/90	Dead head - Miami to Belem
Leg 1	2/7-2/14	Mooring deployment (Beardsley, Chief Sci.)
Leg 2	2/15-2/27	Chemistry, bottom geology
Leg 3	2/28-3/9	Hydrography, water chemistry (Limeburner)
Leg 4	3/10-3/24	Frontal zone study (Geyer)
Leg 5	3/25-3/31	Bottom geology
	4/2-4/8	Dead head - Belem to Puerto Rico

There is potential for other scientists to participate in these cruises, particularly the legs involving physical oceanography. The dead head legs could be used to measure the northward evolution of the Amazon plume waters.

Potential expansion of AMASSEDS to Tie in with Other Studies and Broaden Scientific Scope:

1. It would be beneficial to *tie in the mooring and hydrographic measurements with the North Brazil Current Study*. Possible alternatives:

   a) Add mooring at 100m isobath, using Castro's current meters (see Castro, this volume).

   b) During AMASSEDS cruises, extend hydrographic and Doppler lines across shelf break.

   c) Obtain hydrographic (and perhaps Doppler) measurements on shelf during STACS and other cruises.

2. Pressure and sea level data should be obtained at as many places as possible. Probable and possible locations include:

   a) Santana and Belém tide gauges (probable);

   b) Eli Katz's IES stations (probable);

   c) at planned WHOI moorings (possible);

   d) at possible 100m mooring (possible);

   e) at shelf locations at 0°W and 4°N (unlikely).

   Possibly, tie in measurements with GEOSAT altimetry and use as a basis for numerical model.

3. Meteorological information should be augmented.

   a) All nearby coastal meteorology should be obtained for the cruise periods and deployment, and the local climatology should be assessed.

   b) Possible deployment of NDBC weather buoy, based on comments of Merritt Stevenson.

4. Satellite and aircraft remote sensing:

   a) Archived coastal zone scanner data should be analyzed.

   b) Ground truth should be obtained during AMASSEDS cruises for optical properties of water.

c) A cooperative program for aircraft remote sensing should be proposed, using a scanning radiometer and Brazilian aircraft (see Muller-Karger, this volume).

d) Analysis of LANDSAT imagery (perhaps by Herz) would provide important sediment transport information.

5. Numerical modeling of tides: Resonant tides provide interesting problem, perhaps for cooperative modeling effort between Brazil and U.S. (see Beardsley, Lorenzzetti discussions, this volume).

6. Other drifters would benefit program, but not strongly supported. Perhaps more mooring data would be more important.

7. We need to protect moorings against risk of loss due to shrimp fishing.

8. Nearshore studies. Renato Herz's satellite imagery indicates the importance of the flow across the nearshore, too shallow for the oceanographic ships. While the logistics may be too difficult, measurements and samples in the region between the shore and the 10m isobath would be very useful.

DRIFTERS

R. BEARDSLEY

AMASSEDS deployed two satellite-tracked surface drifters in the Amazon River plume near 1°N, 49°W in August, 1989. The drifters were drogued at 3 m and moved northwest over the shelf until turning offshore near 5°N and continued clockwise around the NBC retroflection. While these AMASSEDS drifters were released to measure transit time of Amazon River water over the Amazon shelf, the subsequent trajectories are providing exciting new indirect evidence of the downstream disperal mechanism of Amazon water in the western equatorial Atlantic described by Muller-Karger et al. (1988). There was general enthusiasm for the release of several additional drifters in the North Brazil Current simultaneously with future AMASSEDS drifter deployment in the Amazon River plume so that concurrent Lagrangian measurements can be made on both sides of the Amazon surface salinity front. Future AMASSEDS drifter releases are planned for February 1990, June 1990, and November 1991.

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WESTERN TROPICAL ATLANTIC STUDIES

E. KATZ

A large number of field programs concentrated in the North Brazil Current and the tropical Atlantic west of 40°W are presently taking place or are scheduled to begin early in 1990. These include the following:

1. PAVASAS II

   An IOUSP cruise consisting of four meridional hydrographic lines between 2°S and 3°N and 42° to 44°W, two hydrographic lines normal to the coast at about 1° and 2°N, and a one-month deployment of a tide gauge on the shelf at 200 m and depth. Scheduled to occur in October 1989 is a repeat of a cruise made in July-Sept 1987, and it is hoped to recur in the boreal fall of 1990. In PAVASAS I, a 35-day tide gauge record was obtained from a sea mount at 0°14'N, 41°13'W.

2. Deep Sea Moorings

   Several records have recently been obtained by the STACS Program from over the Demarara Rise. A cruise completed in September 1989 deployed six new moorings (STACS and Kiel University), three across the NBC meeting the shelf near the equator, and a second set of three meeting the shelf at about 4°N. These are scheduled to be recovered in September 1990 with a possible redeployment for a second year. A seventh mooring (Kiel) may be deployed at 7°N 44°W in 1990. Three moorings across the NBC off Cayenne are planned by ORSTOM (France).

3. Pegasus Array (and Hydrography)

   Twenty-four Pegasus sides are planned by University of Miami and University of New Hampshire in an array bounded by 44°W and the coast, 20°N and the equator. Cruises are scheduled for Jan/Feb, 1990, Aug/Sept, 1990, April/May, 1991, and probably January, 1992. In September 1990, six additional sides may be established by Kiel University. ORSTOM is planning seven sites straddling the equator on the normal to Cayenne. (Beacons were deployed for five sites in September, 1989.)

4. Inverted Echo Sounders

   An array of ten sounders are planned by LDGO. A line of four sounders along 44°W and a line of three across the NBC to 2000m depth at 2°N will be deployed in November, 1989. A second line across the NBC at

6°N (off Cayenne) will be deployed in the spring of 1990. These are scheduled for recovery in the spring of 1991, with a possible extension into 1992.

Recomendations

The major need discussed in this area was that of (a) coordination of the field work coming from so many different institutions (and four countries); and (b) early exposure of preliminary data results to assist one another in interpretation, and eventually synthesis, of the data sets. This is equally true with respect to the AMASSEDS physical oceanographic data. Thus, it is recommended that the U.S. participants will seek funding for travel of all principal investigators to a series of *ad hoc* scientific coordination meetings. It is felt essential to have the first meeting in January 1990, given the already initiated field activity, and to continue with semi-annual meetings for at least two, possibly three years.

BRAZIL-U.S. COLLABORATION IN SPACE-BASED REMOTE SENSING OF THE OCEAN

F. MULLER-KARGER

Collaborating Institutions:

Brazil

- Space Research Institute of Brazil (INPE)
- Oceanographic Institute of the University of São Paulo (IOUSP)

U.S.

- Department of Marine Science of the University of South Florida (USF/MSL)
- Woods Hole Oceanographic Institution (WHOI)
- University of Miami's Rosenstiel School of Marine and Atmospheric Sciences (UM/RSMAS)
- University of South Carolina Belle Baruch Institute (USC)
- National Oceanic and Atmospheric Administration (NOAA/NESDIS)

Collaborating Scientists:

Brazil

- J. Lorenzzetti (INPE)
- M. Vianna (INPE)
- R. Herz (IOUSP)
- L.B. de Miranda (IOUSP)

U.S.

- F. Muller-Karger (USF/MSL)
- R. Beardsley (WHOI)
- W. Geyer (WHOI)
- K. Carder (USF/MSL)
- B. Kjerfve (USC)
- R.V. Legeckis (NOAA/NESDIS)

Outline of Collaboration Program

A joint project on space-borne remote sensing, with airborne and ship-based support, will be established between the Space Research Institute of Brazil (INPE), the Oceanographic Institute of the University of São Paulo (IOUSP), the University of Miami's Rosenstiel School of Marine and Atmospheric Sciences (UM/RSMAS), the Department of Marine Science of the University of South Florida (USF/MSL), and Woods Hole Oceanographic Institution (WHOI). The goal of this collaboration effort is to improve understanding of the processes controlling water motion and sediment transport/deposition in coastal and oceanic environments of the subtropical and equatorial coasts of Brazil, over small scales (meters) to synoptic scales (thousands of kilometers), and over time scales of days to years.

The above institutions will exchange satellite databases covering the coast of Brazil and the tropical and southern Atlantic Ocean. Sharing of data analysis tools for derivation of geophysical parameters (e.g., pigment or sediment concentration, sea surface temperature, etc.) will be part of this agreement.

Collaboration involving the following satellite sensors was found important for oceanographic studies off Brazil:

1. Coastal Zone Color Scanner (CZCS-NIMBUS 7) satellite data:

   USF/MSL was designated by NASA as an archive site for the global CZCS data set. USF/MSL, IOUSP, and INPE will establish a program whereby the data set covering Brazil will be transferred to build a regional archive at the INPE site. A letter of intent is to be written to Marlon Lewis, program manager in Oceanic Productivity, NASA Headquarters, Washington, DC (USA) describing the data exchange. This formal procedure is necessary to ensure smooth transmittal of the satellite data. The exchange includes student training in the use of analysis tools and application of the data at USF/MSL and UM/RSMAS.

   Analysis of the CZCS data set will support other collaborative programs developed during the Brazil-U.S. collaborative effort in physical oceanography and ongoing programs studying the coastal/offshore environment of Brazil.

2. Advanced Very High Resolution Radiometer (AVHRR) and Thematic Mapper (TM) satellite data:

   INPE has data receiving capabilities for NOAA-AVHRR, NOAA-GOES, and LANDSAT Thematic Mapper. Algorithms for remapping the AVHRR data need to be developed, and this will be done in collaboration with USF/MSL and UM/RSMAS. These data will then be used for analysis of the sediment plume exiting the Amazon delta as well as the sea surface temperature patterns of waters along the entire Brazilian coast.

   The TM has a high spatial resolution (30 m) which will provide small-scale feature information in support of field programs in the Amazon delta and other shelf and coastal regions. In particular, the TM data will be used to understand processes of sediment dispersal in this region in support of the AMASSEDS and TOPSUB programs. Processing of these images will proceed at IOUSP, University of South Carolina, and University of South Florida.

   The use of near-infrared AVHRR data and LANDSAT Thematic Mapper data in support of the 1989-1991 field components of the NSF-funded AMASSEDS program (A Multidisciplinary Amazon Shelf Sediment Study) was proposed to NSF recently by investigators of NOAA/NESDIS (R. Legeckis), the University of South Carolina (B.J. Kjerfve), and IOUSP (R. Herz and L.B. de Miranda). This additional component of AMASSEDS would focus on sediment distribution off the Amazon delta.

During the Second Brazil-U.S. workshop on Physical Oceanography, it became clear that areas of interest include the Amazon delta region, the region of bifurcation of the South Equatorial Current, and the coast of south Brazil (South Brazil Bight–SBB). The Brazil-U.S. collaborative agreement includes these areas in a comprehensive remote sensing study of the coasts of Brazil.

3. Airborne scanner validation of space-borne sensor data:

   This project, described in detail in the discussion titled "Brazil-U.S. Collaboration in Airborne Remote Sensing of the Ocean," below, will make use of a small airborne spectral imager to map oceanic features and resolve their optical characteristics. The goal is to use this information, combined with biological (pigment concentration), geological (sediment concentration and composition), and optical oceanographic data to understand the bio-optical characteristics of the patterns observed in Coastal Zone Color Scanner data. Additional benefits are detection of mesoscale features, and guidance for planning the station layout of oceanographic cruises.

   Two instruments are being evaluated for use in this project:

   - The Compact Airborne Spectral Imager (CASI), built in Canada and operated by Borstad Associates (Canada);
   - The Calibrated Airborne Multispectral Scanner (CAMS), built in the U.S. by NASA, and operated by Richard Miller at Stennis Space Flight Center (NASA).

When this information is combined with *in situ* data, flow patterns, mixing, resuspension, and sediment transport processes will become apparent. Also, it will be possible to test hypotheses about the Amazon River plume and its interaction with the North Brazil Current (NBC). The dispersal of suspended sediment, phyto plankton pigments, and dissolved organic material (yellow substances), traced from space and aircraft, may also be used as tracers to map the NBC retroflection and the transport of Amazon water into the North Equatorial Countercurrent.

As detailed in the discussion of airborne remote sensing (below), INPE, USF/MSL, and IOUSP will collaborate in the overflights of the Amazon delta region, the adjacent continental shelf, the coast off northeast Brazil, and the Cabo Frio upwelling region. INPE has agreed to cover aircraft and fuel costs for this study. INPE will provide an INPE aircraft, or will work in collaboration with branches of the Brazilian military to procure the necessary aircraft time.

An official statement from INPE stating the availability of aircraft time/fuel is needed to include in formal proposals to funding agencies.

A part of this component will address ground truth validation of the sensor data. Space on ships studying these areas of interest has been made available through other components of the Brazil-U.S. cooperative agreement on physical oceanography.

4. Microwave remote sensing studies:

   INPE's capabilities in airborne microwave radiometry, once established in 1990, could also be applied in support of the above programs.

BRAZIL-U.S. COLLABORATION IN AIRBORNE REMOTE SENSING OF THE OCEAN

F. MULLER-KARGER

Collaborating Institutions:

Brazil

- Space Research Institute of Brazil (INPE)
- Oceanographic Institute of the University of São Paulo (IOUSP)

U.S.

- Department of Marine Science of the University of South Florida (USF/MSL)
- Woods Hole Oceanographic Institution (WHOI)
- University of Miami's Rosenstiel School of Marine and Atmospheric Sciences (UM/RSMAS)
- University of California, Santa Barbara (UCSB)
- National Aeronautics and Space Administration, Science and Technology Laboratory (NASA/STL, Mississippi)

Collaborating Scientists:

Brazil

- J. Lorenzzetti (INPE)
- M. Vianna (INPE)
- R. Herz (IOUSP)
- L.B. de Miranda (IOUSP)

U.S.

- F. Muller-Karger (USF/MSL)
- R. Beardsley (WHOI)
- W. Geyer (WHOI)
- K. Carder (USF/MSL)
- R. C. Smith (UCSB)
- R. Miller (NASA/STL)

Outline of Collaboration Program

A joint project on airborne remote sensing, with ship-based and satellite support, will be established between the Space Research Institute of Brazil (INPE), the Oceanographic Institute of the University of São Paulo (IOUSP), the Department of Marine Science of the University of South Florida (USF/MSL), Woods Hole Oceanographic Institution(WHOI), the University of Miami's Rosenstiel School of Marine and Atmospheric Sciences (UM/RSMAS), and NASA/STL.

The goal of this collaborative effort is to understand and validate patterns observed in Coastal Zone Color Scanner images of the coast, shelf, and offshore waters surrounding Brazil. The airborne scanner will provide detailed spectral and spatial information on the optical constituents affecting the color of these waters. Ground truth will be provided by ships working off the Amazon delta, in the region of the retroflection of the North Brazil Current, and other areas where ongoing oceanographic studies established under the charter of the Brazil-U.S. collaborative agreement are underway. This information will be examined in the context of the larger spatial coverage provided by satellite sensors. The proposed collaborative satellite data analyses are outlined in a separate paragraph of this agreement.

The combined airborne, ship, and satellite information will help determine the relative importance of phytoplankton pigment, dissolved organic matter, and sediment concentration in modifying the color of the water in areas where the circulation is poorly understood. This information, in turn, is important to understanding of the processes controlling water motion and sediment transport/deposition in the coastal and oceanic environments off Brazil. Eventually, a monitoring program should be instituted to establish a long time series of observations which will resolve large-scale changes associated with possible global climate change.

Two airborne scanners are available that meet the specifications for carrying out the research outlined here. It will be necessary to establish the exact budgets and times of availability for the operation off Brazil. The instruments are:

1. Compact Airborne Spectrographic Imager (CASI)

   This is a Canadian instrument, manufactured by MONITEQ, Ltd., and operated by Borstad Associates (Gary Borstad, president). The CASI is

A statement from INPE establishing the availability of aircraft time is necessary. This will facilitate funding from U.S./Brazil granting agencies for operation of the airborne scanner and support of the ground truth component. INPE agreed to investigate the feasibility of flying their twin-engine aircraft over the Amazon delta and offshelf waters. An alternative to this should be presented, and INPE suggested that perhaps other organs of the Brazilian government—in particular the Brazilian Air Force and Navy—may be interested in participating in the collaboration program by supplying the appropriate aircraft.

ALTIMETER-DERIVED SEA LEVEL STUDIES

J. CARTON

An ongoing analysis of monthly sea level changes throughout the tropical Atlantic conducted at University of Maryland (Carton) and Lamont Doherty Geological Observatory (Katz) has been reported on. Gridded monthly fields have been produced for nearly three years at $1° \times \frac{1}{3}°$ resolution, between 25°S and 25°N, in water deeper than 2250 m. As part of the NASA TOPEX/POSIEDON program, this sea level data has been compared to records from six inverted echo sounders. This study has shown that the altimeter-derived sea level data is sufficiently accurate to describe large scale (>150 km) seasonal sea level and geostrophic velocity changes in the deep ocean. An important aspect of the U.S./Brazil bilateral exchange can be the transfer of this altimeter sea level gridded data to INPE. A goal of this exchange should be to encourage development of altimeter sea level data processing in Brazil.

Two errors limit the usefulness of altimeter-derived sea level data in water shallower than 2250 m, where it could contribute to an understanding of coastal processes. The first is the error introduced by the large sea level changes due to (unknown) tides. An analysis of the coastal tides will be needed in order to correct for this error. The second error is due to the rapid changes in geoid associated with shelf topography. Studies will be proposed to determine how far inshore the altimeter-derived sea level data can be usefully extended. Calibration of the data by coincident positioning of instruments along satellite tracks will be crucial to this project.

BRAZIL-U.S. JOINT MODELLING STUDIES

M. Vianna and J. Carton

Collaboration on model development and application to predict and explain ocean circulation within areas of current bilateral interest was agreed upon.

1. Continental Shelf Circulation Modelling

   - Application and testing of existing models to determine tide-driven and wind-driven circulation over the northeast Brazilian shelf, including the Amazon outflow area, will be implemented by J. Lorenzzetti of INPE, in support of the AMASSEDS and TopSub projects. Collaboration between INPE and Woods Hole, under the direction of R. Beardsley, has been agreed upon.
   - M. Vianna and P. Holvorcem (INPE) have begun development of a boundary element model for shelf circulation. First applications of the model will focus on the north-northeast Brazilian continental shelf, in support of the same projects.
   - Other collaboration between INPE and Woods Hole is envisioned, especially on the use of high-resolution graphics and workstation display software.

2. Tropical Ocean Circulation Modelling

   - Although at the 1987 Brazil/U.S. Workshop in New Hampshire a bilateral modelling study group was suggested as feasible, at the 1989 workshop only INPE reported on initial results, using the boundary element model. Efforts by M. Vianna and P. Holvorcem of INPE to explain the genesis of the NECC retroflection is continuing.
   - General circulation modelling studies of the tropical Atlantic are continuing at University of Maryland (J. Carton) and the Geophysical Fluid Dynamics Laboratory (G. Philander). The numerical model used solves the primitive equations with a horizontal resolution of $1^\circ \times \frac{1}{3}^\circ$ and a vertical resolution of 10 m near-surface. The model predicts three-dimensional temperature, salinity, and vector velocity in response to atmospheric forcing.
   - At the University of Maryland a study is being proposed to examine the seasonal cycle of freshwater input, storage, and transport in the ocean. An important aspect of this project will be to examine the impact of Amazon and Orinoco runoff on near-surface processes in the open ocean.
   - A second project is being developed at University of Maryland (J. Carton) to examine the relationship between seasonal changes in the

North Brazil Current and the North Equatorial Countercurrent, and seasonal changes in the wind field. This latter project will include an analysis of the near-coastal circulation based on data assimilation techniques, using temperature, salinity, and eventually current observations to constrain the numerical simulation.

- Collaboration between Vianna and Holvorcem, and U.S. investigators from NOAA, University of Miami, University of South Florida, and University of Maryland, will be implemented.

FUTURE (LONG-TERM) COLLABORATIONS:

BRAZIL/U.S. COLLABORATIVE STUDIES OF THE BRAZIL CURRENT

Y. IKEDA, W. JOHNS, K. LEAMAN, A. MASCARENHAS

Interests in long-term studies of the Brazil Current along the South Brazilian Bight were expressed by both Brazilian and U.S. scientists. Three regions were identified where the establishment of long-term (two- to three-year) monitoring sections involving the use of moored instrumentation and repeated hydrographic/Pegasus stations were felt to be logistically feasible and scientifically important. The observations along any one section would ideally consist of limited moored current meter measurements (two to three moorings) to monitor temporal variability, and approximately ten Pegasus/hydrography stations across the current to measure the detailed velocity and water mass structure, to be occupied on approximately a quarterly basis. Shipboard work would be done primarily from Brazilian vessels, while current meter and other resources would be contributed and shared by both Brazilian and U.S. investigators.

The first two section locations are near 23°S and 31°S, where an earlier Brazil/U.S. joint program yielded a number of hydrographic/XBT and absolute velocity sections across the Brazil Current. Reestablishment of one or both of these sections was considered to be of high priority to build on the previous observations and to obtain a more robust description of the vertical structure, transport, and seasonal variability of the Brazil Current at these locations. Recent oil drilling activity over the continental shelf and slope off Cabo de São Tome, near the 23°S section, also makes detailed observations of the Brazil Current at this location economically and environmentally important. It was decided to focus Brazil/U.S. efforts on these two regions and to explore potential funding for this work from U.S. and Brazilian agencies.

The third section discussed was near 27°S, where Brazilian scientists have proposed a combined mooring/hydrography/Pegasus effort as part of the international WOCE program. German (FRG) scientists have also proposed a WOCE contibution to the moored current meter observations along this section, and are actively collaborating with Brazilian scientists in planning this program. Significant participation by U.S. scientists in this section is not anticipated at this time, although due to strong mutual interests it was agreed that contacts would be closely maintained as the WOCE plans evolve, to evaluate whether a U.S. contribution here would be beneficial.

SHORT-TERM COOPERATION NEEDED FOR UNIVERSIDADE DO RIO GRANDE (FURG)

O. MÜLLER

1. Tri-dimensional modeling for salt dispersion at the estuarine zone of Patos Lagoon.
2. Plans for the near future, which could also involve bilateral cooperation, include continental shelf circulation studies between 28°S and 34°S.
   - Cruises (FURG)
   - Moorings (FURG)
   - Remote sensing (Coop)
   - Modeling (Coop)
3. FURG could offer:
   - People prepared for satellite imagery interpretation (LANDSAT, CZCS);
   - Shiptime for any cruise of special interest in the above-mentioned area;
   - 30°S tide gauge (mainly related to WOCE plans).

TECHNOLOGY TRANSFER

R. BONETO

1. Introduction

Brazilian technical infrastructure in physical oceanography was reviewed as part of the Second Brazil/U.S. Workshop on Physical Oceanography. Two Brazilian oceanographic instrumentation laboratories showed capabilities to offer support to the projects to be developed under the U.S.-Brazil Cooperation Program:

- Instrumentation Laboratory of Instituto Oceanográfico da Universidade de São Paulo (IOUSP)
- Instrumentation Laboratory of Instituto de Pesquisas Espaciais (INPE)

Existing strengths and related problems were discussed, and a summary is presented below.

2. Existing Strengths

The laboratories at IOUSP and INPE have been involved with oceanographic instrumentation for several years and can offer support in development, calibration, maintenance and operation of instruments during field work.

The main development projects carried on recently have been:

- meteorological-oceanographic buoys with satellite telemetry and related test and support equipment;
- data acquisition systems for several oceanographic instruments;
- acoustic and timed releases;
- buoys for signalizing and positioning;
- shallow water current meters.

A calibration facility is being established at IOUSP and should start work next year.

Both groups have experience in maintenance of oceanographic instruments. Also, they have experience in deployment and recovery of some kinds of instruments as well as operation of onboard systems.

3. Problem Areas

Several problem areas were identified during the discussion:

- lack of locally available specialized sensors (pressure, temperature, conductivity, acoustic transducers, etc.) and unacceptably long lead-time needed to buy such sensors abroad;

- lack of standards and facilities for calibration of instruments;
- difficulty in accessing technical reports and related information;
- personnel training, exchange and expansion.

4. Recommendations

   (a) Equipment

   - A way should be found to accelerate the process of importing specialized parts, when not available locally, so as to reduce instrument development time.
   - Brazilian industries should be encouraged to develop specialized sensors and parts.
   - As part of a joint research project, the investigators involved should be able to share equipment, support and other resources on an equal basis. This might involve, for example, the integration of a measurement system with components produced in both the USA and Brazil.

   (b) Calibration

   - Instruments should be sent to calibration facilities in the USA until it is possible to do the necessary calibration locally.

   (c) Access to Technical Literature

   It is important to:

   - identify the most important sources of technical information and have them available to Brazilian laboratories (e.g., *Journal of Atmospheric and Oceanic Technology*);
   - establish contact with U.S. companies for better exchange of information on current development of products.

   (d) Personnel Training, Exchange and Expansion

   The main areas of interest are:

   - calibration technology;
   - sensor development;
   - mooring technology;
   - data acquisition systems;
   - telemetry (radio, satellite and acoustic).

   The reciprocal training of personnel should be facilitated by means of:

   - short information visits;
   - cruises (to gain operational experience);
   - applications training courses (two weeks to two months);

• longer-term schooling (one year or more).

It is extremely important to facilitate the exchange of technical/engineering personnel in the same manner as is now done with scientific personnel.

Due to the great amount of work involved in the activities of several projects planned to be carried out in the near future, it is strongly recommended that the Brazilian technical staff be increased.

APPENDIX A.

LIST OF REGISTRANTS

Robert Beardsley (WHOI, U.S.)
Reinaldo F. Boneto (IOUSP, Brazil)
Wendell Brown (UNH, U.S.)
John Bruce (NORDA, U.S.)
Alexandre P. Cabral (INPE, Brazil)
Edmo Campos (RSMAS/UM, U.S.)
James Carton (UMD, U.S.)
Pedro R. de Carvalho (INPE, Brazil)
Wladimir R. Esposito (IOUSP, Brazil)
Belmiro Mendes de Castro Filho (IOUSP, Brazil)
Manuel Fiadeiro (NCAR, U.S.)
Wayne Geyer (WHOI, U.S.)
Renato Herz (IOUSP, Brazil)
Paulo R.C. Holvorcem (INPE, Brazil)
Joseph Harari (IOUSP, Brazil)
William Johns (RSMAS/UM, U.S.)
Eli Joel Katz (LDGO, U.S.)
Kevin Leaman (RSMAS/UM, U.S.)
João Antonio Lorenzzetti (INPE, Brazil)
Affonso da S. Mascarenhas, Jr. (IOUSP, Brazil)
Afranio R. de Mesquita (IOUSP, Brazil)
Luiz Bruner de Miranda (IOUSP, Brazil)
Osmar Müller (FURG, Brazil)
Frank Muller-Karger (USF, U.S.)
Luiz Vianna Nonato (IOUSP, Brazil)
Ulf Palme (INPE, Brazil)
Claudio Solano Pereira (INPE, Brazil)
Olga T. Sato (IOUSP, Brazil)
Carlos L. da Silva, Jr. (INPE, Brazil)
Reynaldo Solewicz (INPE, Brazil)
José Luiz Stech (INPE, Brazil)
Marcio L. Vianna (INPE, Brazil)

FURG – Federal Universidade do Rio Grande
INPE – Instituto de Pesquisas Espaciais
IOUSP – Instituto Oceanográfico, Universidade de São Paulo
LDGO – Lamont Doherty Geological Observatory, Columbia University
NCAR – National Center for Atmospheric Research
NORDA – Naval Oceanographic Research and Development Activity
RSMAS/UM – Rosensteil School of Marine and Atmospheric Science, University of Miami
UMD – University of Maryland
UNH – University of New Hampshire
USF – University of South Florida
WHOI – Woods Hole Oceanographic Institution

APPENDIX B.

WORKSHOP SCHEDULE

Monday, September 18, 1989

09:00–10:00 h: Registration
10:00–10:30 h: Opening Section - Prof. Dr. Antonio Guimarães Ferri
10:30–10:45 h: Administrative announcements
10:45–11:00 h: Coffee break
11:00–11:20 h: Designation of the chairmen of the sections

Participant Talks (Section I)

11:20–11:40 h: *Hydrographic observations in the Amazon outflow, August 1989*
- Richard Limeburner and Robert Beardsley (WHOI)

11:40–12:00 h: *Oceanic tides*
- Afranio R. de Mesquita and Joseph Harari (IOUSP)

12:00–14:00 h: *Lunch*

Participant Talks (Section II)

14:00–14:20 h: *Mixing in the Amazon plume: Some early results of AMASSEDS*
- Wayne Geyer (WHOI)

14:20–14:40 h: *On the variability of the mean sea level on coastal areas*
- Joseph Harari and Afranio R. de Mesquita (IOUSP)

14:40–15:00 h: *Near equatorial eddies off South America*
- John G. Bruce (NORDA)

15:00–15:20 h: Coffee break

15:20–15:40 h: *Sandstream on the northeast Brazilian shelf*
- Marcio L. Vianna, Reynaldo Solewicz and Alexandre P. Cabral (INPE)

15:40–16:00 h: *Satellite observations of the NBC retroflection and Amazon water dispersal*
- Frank E. Muller-Karger (USF)

16:00–16:20 h: *TOPSUB - A multidisciplinary study of the shaping of the sea floor by ocean currents and the impact of topographic interactions on circulation over the N-NE Brazilian continental shelf*
- Marcio L. Vianna (INPE)

16:20–16:40 h: Coffee break

16:40–17:00 h: *The equatorial Atlantic circulation according to the CME*
- Manuel Fiadeiro (NCAR)

17:00–17:20 h: *The Rio Grande do Sul coastal zone–projects, results, and perspectives*
- Osmar Müller (FURG)

17:20–17:40 h: *The structure of currents in the western tropical Atlantic Ocean*
- Wendell S. Brown (UNH)

17:40–18:00 h: *Low frequency variability and wave scattering off abrupt topography: Implications for western boundary currents*
- Kevin Leaman (RSMAS/UM)

18:00–18:20 h: *Applications of the inverted echo sounder deployed in the western equatorial Atlantic*
- Eli Joel Katz (LDGO)

Tuesday, September 19, 1989

Participant Talks (Section III)

09:00–09:20 h: *A model comparison of winter circulation dynamics of the SAB (USA) and SBB (Brazil)*
- João Antonio Lorenzzetti and José Luiz Stech (INPE)

09:20–09:40 h: *Subtidal variability on the south Brazil Bight*
- Belmiro Mendes de Castro Filho (IOUSP)

09:40–10:00 h: *Hydrography and volume transport on the eastern Brazilian coast*
- Luiz Bruner de Miranda (IOUSP)

10:00–10:20 h: *Boundary element approach to ocean circulation modeling*
- Marcio L. Vianna and Paulo R.C. Holvorcem (INPE)

10:20–10:40 h: *Estimates of the zonal slope and seasonal transport of the Atlantic North Equatorial Countercurrent*
- James Carton (UMD) and Eli Joel Katz (LDGO)

10:40–11:00 h: Coffee break

11:00–11:20 h: *Numerical simulation of a response of an oceanic front to a mesoscale atmospheric forcing*
- Claudio Solano Pereira (INPE) and Affonso da S. Mascarenhas, Jr. (IOUSP)

11:20–11:40 h: *A low-cost, low-power data acquisition system*
- Reinaldo F. Boneto, Luiz Vianna Nonato and Wladimir R. Esposito (IOUSP)

11:40–12:00 h: *Is the Sverdrup relation valid in the South Atlantic?*
- Affonso da S. Mascarenhas, Jr. and Olga T. Sato (IOUSP)

12:00–12:20 h: *Buoy-based met-ocean data acquisition system development at INPE*
- Pedro R. de Carvalho, Merritt R. Stevenson and Carlos L. da Silva, Jr. (INPE)

12:20–14:20 h: Lunch

Participant Talks (Section IV)

14:20–14:40 h: *Towards a capability of mapping sea surface parameter fields by airborne microwave radiometers*
- Ulf Palme (INPE)

14:40–15:00 h: *Variability of the North Brazil Current and North Equatorial Countercurrent off French Guiana: 1987-1988*
- William E. Johns (RSMAS/UM)

15:00–15:20 h: *Reflection of equatorial waves from oceanic boundaries of arbitrary shape*
- Paulo R.C. Holvorcem (INPE)

15:20–15:40 h: *Stationary Rossby waves in western boundary current extensions*
- Edmo Campos, D. Olson and D. Boudra (RSMAS/UM)

15:40–16:00 h: Coffee break

16:00–16:20 h: *Dispersion processes of the suspended material transported by Barra Norte coastal water–Amazon River*
- Renato Herz (IOUSP)

16:20–18:00 h: Issues raised during the sections from the point of view of the Brazilian and U.S. convenors. Selection of the working areas or subjects, and selection of a coordinator for each one.

Wednesday, September 20, 1989 (Provisional schedule)

Morning Session

09:00–12:00 h: Small group meetings
12:00–14:00 h: Lunch

Afternoon Session

14:00–18:00 h: Preliminary plans for cooperative research. Written reports.

Thursday, September 21, 1989

Morning Session

09:00–10:00 h: Plenary session–discussion of the plans and issues raised during the small group meetings
10:00–12:00 h: First draft of a document discussing strategies, research plans, and cooperation
12:00–14:00 h: Lunch

Afternoon Session

14:00–16:00 h: Final discussions
16:00–18:00 h: Closure section–Prof. Antonio Guimarães Ferri
18:00 h: Reception offered by the director of IOUSP in the Faculty Club

Friday, September 22, 1989

09:00 h: Trip to INPE leaving from Lorena Suite Service

APPENDIX C.

PARTICIPANT ADDRESS LIST

Brazilian Participants:

Reinaldo Fernandes Boneto, Instituto Oceanográfico, Universidade de São Paulo, Praca do Oceanográfico, 191, Cidade Universitaria - Butanta, São Paulo, S.P. - CEP 05508 - Brasil; Telephone: (011) 813-3222 ext. 2386; Telemail: IOUSP.PO

Alexandre P. Cabral, Instituto de Pesquisas Espaciais, Avenida dos Astronautas, 1758, C.P. 515, Jardim da Granja, São José dos Campos, São Paulo - CEP 12201 - Brasil; Telephone: (0123) 22-9977 ext. 557; Telemail: INPE.MET

Pedro R. de Carvalho, Instituto de Pesquisas Espaciais, Avenida dos Astronautas, 1758, C.P. 515, Jardim da Granja, São José dos Campos, São Paulo - CEP 12201 - Brasil; Telephone: (0123) 22-9977 ext. 380; Telemail: INPE.MET

Belmiro Mendes de Castro Filho, Instituto Oceanográfico, Universidade de São Paulo, Praca do Oceanográfico, 191, Cidade Universitaria - Butanta, São Paulo, S.P. - CEP 05508 - Brasil; Telephone: (011) 813-3222 ext. 2387; Telemail: IOUSP.PO

Wladimir R. Esposito, Instituto Oceanográfico, Universidade de São Paulo, Praca do Oceanográfico, 191, Cidade Universitaria - Butanta, São Paulo, S.P. - CEP 05508 - Brasil; Telephone: (011) 813-3222 ext. 2386; Telemail: IOUSP.PO

Renato Herz, Instituto Oceanográfico, Universidade de São Paulo, Praca do Oceanográfico, 191, Cidade Universitaria - Butanta, São Paulo, S.P. - CEP 05508 - Brasil; Telephone: (011) 813-3222 ext. 2378; Telemail: IOUSP.PO

Paulo R.C. Holvorcem, Instituto de Pesquisas Espaciais, Avenida dos Astronautas, 1758, C.P. 515, São José dos Campos, São Paulo - CEP 12201 - Brasil; Telephone: (0123) 22-9977 ext. 557; Telemail: INPE.MET

Joseph Harari, Instituto Oceanográfico, Universidade de São Paulo, Praca do Oceanográfico, 191, Cidade Universitaria - Butanta, São Paulo, S.P. - CEP 05508 - Brasil; Telephone: (011) 813-3222 ext. 2387; Telemail: IOUSP.PO

Yoshimine Ikeda, Instituto Oceanográfico, Universidade de São Paulo, P.O. Box 9075, Praca do Oceanográfico, 191, Cidade Universitaria - Butanta, São Paulo, S.P. - CEP 05508, Brasil; Telephone: (011) 813- 3222 ext. 2363; Telemail: IOUSP.PO

João Antonio Lorenzzetti, Instituto de Pesquisas Espaciais, Avenida dos Astronautas, 1758, C.P. 515, Jardim da Granja, São José dos Campos, São Paulo - CEP 12201 - Brasil; Telephone: (0123) 22-9977 ext. 290; Telemail: INPE.MET

Affonso da Silveira Mascarenhas, Jr., Instituto Oceanográfico, Universidade de São Paulo, Praca do Oceanográfico, 191, Cidade Universitaria-Butanta, São Paulo, S.P. - CEP 05508 - Brasil; Telephone: (011) 813-3222 ext. 2328; Telemail: IOUSP.PO

Afranio Rubems de Mesquita, Instituto Oceanográfico, Universidade de São Paulo, Praca do Oceanográfico, 191, Cidade Universitaria - Butanta, São Paulo, S.P. - CEP 05508, Brasil; Telephone: (011) 813-3222 ext. 2327; Telemail: IOUSP.PO

Luiz Bruner de Miranda, Instituto Oceanográfico, Universidade de São Paulo, Praca do Oceanográfico, 191, Cidade Universitaria - Butanta, São Paulo, S.P. - CEP 05508 - Brasil; Telephone: (011) 813- 3222 ext. 2328; Telemail: IOUSP.PO

Sadako Y. Miyao (M.Sc.), Instituto Oceanográfico, Universidade de São Paulo, Praca do Oceanográfico, 191, Cidade Universitaria - Butanta, São Paulo, S.P. - CEP 05508 - Brasil; Telephone: (011) 813- 3222 ext. 2387; Telemail: IOUSP.PO

Osmar Müller, Laboratório Oceanografia Fisica, Universidade do Rio Grande, C.P. 474, 96.200 - Rio Grande - RS, Brasil; Telephone: (0532) 32-87-11 ext. 70, 31

Luiz Vianna Nonato, Instituto Oceanográfico, Universidade de São Paulo, Praca do Oceanográfico, 191, Cidade Universitaria - Butanta, São Paulo, S.P. - CEP 05508 - Brasil; Telephone: (011) 813- 3222 ext. 2386; Telemail: IOUSP.PO

Ulf Palme, Instituto de Pesquisas Espaciais, Avenida dos Astronautas, 1758, C.P. 515, Jardim da Granja, São José dos Campos, São Paulo - CEP 12201 - Brasil; Telephone: (0123) 22-9977 ext. 393; Telemail: INPE.MET

Claudio Solano Pereira, Instituto de Pesquisas Espaciais, Avenida dos Astronautas, 1758, C.P. 515, Jardim da Granja, São José dos Campos, São Paulo - CEP 12201 - Brasil; Telephone: (0123) 22-9977 ext. 506; Telemail: INPE.MET

Nuno Pereira Filho (M.Sc.), Instituto Oceanográfico, Universidade de São Paulo, Praca do Oceanográfico, 191, Cidade Universitaria - Butanta, São Paulo, S.P. - CEP 05508 - Brasil; Telephone: (011) 813- 3222 ext. 2328; Telemail: IOUSP.PO

Olga T. Sato, Instituto Oceanográfico, Universidade de São Paulo, Praca do Oceanográfico, 191, Cidade Universitaria - Butanta, São Paulo, S.P. - CEP 05508 - Brasil; Telephone: (011) 813-3222; Telemail: IOUSP.PO

Carlos L. da Silva, Jr., Instituto de Pesquisas Espaciais, Avenida dos Astronautas, 1758, C.P. 515, Jardim da Granja, São José dos Campos, São Paulo - CEP 12201 - Brasil; Telephone: (0123) 22-9977 ext. 380; Telemail: INPE.MET

Reynaldo Solewicz, Rua Senador Vergueiro, 128/1004, Flamengo - CEP 22230 - Rio de Janeiro, RJ - Brasil; Telephone: (021) 225-0038

José Luiz Stech, Instituto de Pesquisas Espaciais, Avenida dos Astronautas, 1758, J. da Granja, São José dos Campos, São Paulo - CEP 12201 - Brasil; Telephone: (0123) 22-9977 ext. 557; Telemail: INPE.MET

Marcio L. Vianna, Instituto de Pesquisas Espaciais, Avenida dos Astronautas, 1758, C.P. 515, São José dos Campos, São Paulo - CEP 12201 - Bransil; Telephone: (0123) 22-9977 ext. 557; Telemail: INPE.MET

U.S. Participants:

Robert Beardsley, Clark Laboratory, Woods Hole Oceanographic Institution, Woods Hole, MA 02543, U.S.A.; Telephone: (508) 548-1400 ext. 2487; Telemail: R.BEARDSLEY

Wendell Brown, Ocean Process Analysis Laboratory, Science and Engineering Research Building, University of New Hampshire, Durham, NH 03824, U.S.A.; Telephone: (603) 862-3153; Telemail: UNH.OCEAN; Fax: (603) 862-1915

John Bruce, CODE MTA, NAVOCEANO, Stennis Space Center, NSTL, Mississippi 39522, U.S.A.; Telephone: (601) 688-5185

Edmo Campos, RSMAS/MPO, University of Miami, 4600 Rickenbacker Causeway, Miami, FL 33149, U.S.A.

James Carton, Department of Meteorology, University of Maryland, College Park, MD 20742, U.S.A.; Telephone: (301) 454-5290; Telemail: J.CARTON

Manuel Fiadeiro, Oceanography Section, National Center for Atmospheric Research, P.O. Box 3000, Boulder, CO 80307-3000, U.S.A.; Telephone: (303) 497-1307

Wayne Geyer, Ocean Engineering, Woods Hole Oceanographic Institution, Woods Hole, MA 02543, U.S.A.; Telephone: (508) 548-1400 ext. 2868; Telemail: R.GEYER

William Johns, RSMAS/MPO, University of Miami, 4600 Rickenbacker Causeway, Miami, FL 33149, U.S.A.; Telephone: (305) 361-4054 Telemail: W.JOHNS; Fax: (305) 361-4622

Eli Katz, Lamont Doherty Geological Observatory, Columbia University, Palisades, NY 10964, U.S.A.; Telephone: (914) 359-2900 x539/368; Telemail: E.KATZ

Kevin Leaman, RSMAS/MPO, University of Miami, 4600 Rickenbacker Causeway, Miami, FL 33149, U.S.A.; Telephone: (305) 361-4102; Telemail: K.LEAMAN

Frank Muller-Karger, Department of Marine Science, University of South Florida, 140 Seventh Avenue South, St. Petersburg, FL 33701, U.S.A.; Telephone: (813) 893-9186; Fax: (813) 893-9189; Telemail: F.MULLER.KARGER